



Standard Test Method for Measurement of Smoke Obscuration Using a Conical Radiant Source in a Single Closed Chamber, With the Test Specimen Oriented Horizontally¹

This standard is issued under the fixed designation E 1995; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This is a fire-test-response standard.

1.2 This test method provides a means of measuring smoke obscuration resulting from subjecting essentially flat materials, products, or assemblies (including surface finishes), not exceeding 25 mm [1 in.] in thickness, in a horizontal orientation, exposed to specified levels of thermal irradiance, from a conical heater, in the presence of a pilot flame, in a single closed chamber. Optional testing modes exclude the pilot flame.

1.3 The principal fire-test-response characteristic obtained from this test method is the specific optical density of smoke from the specimens tested, which is obtained as a function of time, for a period of 10 min.

1.4 An optional fire-test-response characteristic measurable with this test method is the mass optical density (see **Annex A1**), which is the specific optical density of smoke divided by the mass lost by the specimens during the test.

1.5 The fire-test-response characteristics obtained from this test are specific to the specimen tested, in the form and thickness tested, and are not an inherent property of the material, product, or assembly.

1.6 This test method does not provide information on the fire performance of the test specimens under fire conditions other than those conditions specified in this test method. For limitations of this test method, see **5.5**.

1.7 Use the SI system of units in referee decisions; see **IEEE/ASTM SI-10**. The inch-pound units given in brackets are for information only.

1.8 *This test method is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.*

1.9 Fire testing of products and materials is inherently hazardous, and adequate safeguards for personnel and property shall be employed in conducting these tests. This test method may involve hazardous materials, operations, and equipment. See also **6.2.1.2**, **Section 7**, and **11.7.2**.

1.10 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*²

D 2843 Test Method for Density of Smoke from the Burning or Decomposition of Plastics

D 4100 Test Method for Gravimetric Determination of Smoke Particulates from Combustion of Plastic Materials³

D 5424 Test Method for Smoke Obscuration of Insulating Materials Contained in Electrical or Optical Fiber Cables When Burning in a Vertical Cable Tray Configuration

E 84 Test Method for Surface Burning Characteristics of Building Materials

E 176 Terminology of Fire Standards

E 603 Guide for Room Fire Experiments

E 662 Test Method for Specific Optical Density of Smoke Generated by Solid Materials

E 906 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using a Thermopile Method

E 1354 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter

E 1474 Test Method for Determining the Heat Release Rate of Upholstered Furniture and Mattress Components or Composites Using a Bench Scale Oxygen Consumption Calorimeter

¹ This test method is under the jurisdiction of ASTM Committee E05 on Fire Standards and is the direct responsibility of Subcommittee E05.21 on Smoke and Combustion Products.

Current edition approved March 1, 2008. Published April 2008. Originally approved in 1998. Last previous edition approved in 2004 as E 1995 - 04a.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Withdrawn.

E 1537 Test Method for Fire Testing of Upholstered Furniture

E 1590 Test Method for Fire Testing of Mattresses

IEEE/ASTM SI-10 Practice for Use of the International System of Units (SI): The Modernized Metric System

2.2 *ISO Standards*:⁴

ISO Guide 52—Glossary of Fire Terms and Definitions

ISO 3261 Fire Tests—Vocabulary³

ISO 5659-2 Determination of Specific Optical Density by a Single-Chamber Test

ISO 5725 Precision of Test Methods—Determination of Repeatability and Reproducibility for Standard Test Method by Interlaboratory Tests

2.3 *British Standards*:

BS 6809 Method of Calibration of Radiometers for Use in Fire Testing⁵

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology **E 176** and **ISO 3261**. In case of conflict, the definitions given in Terminology **E 176** shall prevail.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *assembly, n*—a unit or structure composed of a combination of materials or products, or both.

3.2.2 *continuous (as related to data acquisition), adj*—conducted at data collection intervals of 5s or less.

3.2.3 *essentially flat surface, n*—surface where the irregularity from a plane does not exceed ± 1 mm.

3.2.4 *exposed surface, n*—that surface of the specimen subjected to the incident heat.

3.2.5 *flaming mode, n*—the mode of testing that uses a pilot flame.

3.2.6 *ignition, n*—the initiation of combustion.

3.2.6.1 *Discussion*—The combustion may be evidenced by glow, flame, detonation, or explosion. The combustion may be sustained or transient.

3.2.7 *mass optical density, n*—the ratio of the optical density of smoke and the mass loss of the test specimen, multiplied by the volume of the test chamber and divided by the length of the light path.

3.2.7.1 *Discussion*—The mass optical density as determined in this test method is not an intrinsic material property; it is a function of the test procedure and conditions used.

3.2.8 *Nonflaming mode, n*—the mode of testing that does not use a pilot flame.

3.2.9 *sample, n*—an amount of the material, product, or assembly, to be tested, which is representative of the item as a whole.

3.2.10 *smoke obscuration, n*—the reduction in visibility due to smoke (**ISO Guide 52**).

3.2.11 *specimen, n*—the actual section of material, product, or assembly, to be placed in the test apparatus.

3.2.12 *time to ignition, n*—time between the start of the test and the presence of a flame on the specimen surface for a period of at least 4s.

4. Summary of Test Method

4.1 This test method assesses the reduction of light by smoke obscuration from a burning sample. The test method employs a conically-shaped, electrically-heated, radiant-energy source to produce irradiance levels of 25 and 50 kW/m², averaged over the center of the exposed surface of an essentially flat specimen, and mounted horizontally inside a closed chamber. The equipment is suitable for testing at irradiance levels of up to 50 kW/m².

4.2 The specimen is 75 by 75 mm [3 by 3 in.], at a thickness not exceeding 25 mm [1 in.] and is mounted horizontally within a holder.

4.3 The exposure is conducted in the presence or in the absence of a pilot flame (see details in **6.3.6**). If a pilot flame is used for ignition, the test is deemed to be in the “flaming” mode; if a pilot flame is not used, the test is deemed to be in the “nonflaming” mode.

4.4 The test specimens are exposed to flaming or nonflaming conditions within a closed chamber. A photometric system with a vertical light path is used to measure the varying light transmission as smoke accumulates. The light transmittance measurements are used to calculate the specific optical density of the smoke generated during the test.

4.5 The specimens are exposed to two conditions, out of the four standard exposure conditions, to be chosen by the test requester. The four standard exposure conditions are: flaming mode at an irradiance of 25 kW/m², flaming mode at an irradiance of 50 kW/m²; nonflaming mode at an irradiance of 25 kW/m²; and, nonflaming mode at an irradiance of 50 kW/m². Unless specified otherwise, conduct testing in the two flaming mode exposure conditions (see **8.3**, **X1.3** and **X1.4**). Exposures to other irradiances also are possible.

4.6 Mass optical density is an optional fire-test-response characteristic obtainable from this test method, by using a load cell, which continuously monitors the mass of the test specimen (see **Annex A1**).

5. Significance and Use

5.1 This test method provides a means for determining the specific optical density of the smoke generated by specimens of materials, products, or assemblies under the specified exposure conditions. Values determined by this test are specific to the specimen in the form and thickness tested and are not inherent fundamental properties of the material, product, or assembly tested.

5.2 This test method uses a photometric scale to measure smoke obscuration, which is similar to the optical density scale for human vision. The test method does not measure physiological aspects associated with vision.

5.3 At the present time no basis exists for predicting the smoke obscuration to be generated by the specimens upon exposure to heat or flame under any fire conditions other than those specified. Moreover, as with many smoke obscuration test methods, the correlation with measurements by other test methods has not been established.

⁴ Available from International Standardization Organization, P.O. Box 56, CH-1211; Geneva 20, Switzerland, or from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

⁵ Available from British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K.

5.4 The current smoke density chamber test, Test Method E 662, is used by specifiers of floor coverings and in the rail transportation industries. The measurement of smoke obscuration is important to the researcher and the product development scientist. This test method, which incorporates improvements over Test Method E 662, also will increase the usefulness of smoke obscuration measurements to the specifier and to product manufacturers.

5.4.1 The following are improvements offered by this test method over Test Method E 662: the horizontal specimen orientation solves the problem of melting and flaming drips from vertically oriented specimens; the conical heat source provides a more uniform heat input; the heat input can be varied over a range of up to 50 kW/m², rather than having a fixed value of 25 kW/m²; and, the (optional) load cell permits calculations to be made of mass optical density, which associates the smoke obscuration fire-test-response characteristic measured with the mass loss.

5.5 Limitations⁶:

5.5.1 The following behavior during a test renders that test invalid: a specimen being displaced from the zone of controlled irradiance so as to touch the pilot burner or the pilot flame; extinction of the pilot flame (even for a short period of time) in the flaming mode; molten material overflowing the specimen holder; or, self-ignition in the nonflaming mode.

5.5.2 As is usual in small-scale test methods, results obtained from this test method have proven to be affected by variations in specimen geometry, surface orientation, thickness (either overall or individual layer), mass, and composition.

5.5.3 The results of the test apply only to the thickness of the specimen as tested. No simple mathematical formula exists to calculate the specific optical density of a specimen at a specimen thickness different from the thickness at which it was tested. The literature contains some information on a relationship between optical density and specimen thickness [1].⁷

5.5.4 Results obtained from this test method are affected by variations in the position of the specimen and radiometer relative to the radiant heat source, since the relative positioning affects the radiant heat flux (see also [Appendix X2](#)).

5.5.5 The test results have proven sensitive to excessive accumulations of residue in the chamber, which serve as additional insulators, tending to reduce normally expected condensation of the aerosol, thereby raising the measured specific optical density (see [5.5.8.3](#) and [11.1.2](#)).

5.5.6 The measurements obtained have also proven sensitive to differences in conditioning (see [Section 10](#)). Many materials, products, or assemblies, such as some carpeting, wood, plastics, or textiles, require long periods to attain equilibrium (constant weight) even in a forced-draft conditioning chamber. This sensitivity reflects the inherent natural variability of the sample and is not specific to the test method.

5.5.7 In this procedure, the specimens are subjected to one or more specific sets of laboratory test conditions. If different

test conditions are substituted or the end-use conditions are changed, it is not necessarily possible by or from this test method to predict changes in the fire-test-response characteristics measured; therefore, the results are valid only for the fire test exposure conditions described in this procedure.

5.5.8 This test method solves some limitations associated with other closed chamber test methods, such as Test Method E 662 [\[2-5\]](#) (see [5.4.1](#)). The test method retains some limitations related to closed chamber tests, as detailed in [5.5.8.1-5.5.8.5](#).

5.5.8.1 Information relating the specific optical density obtained by this test method to the mass lost by the specimen during the test is possible only by using the (optional) load cell, to determine the mass optical density (see [Annex A1](#)).

5.5.8.2 All specimens consume oxygen when combusted. The smoke generation of some specimens (especially those undergoing rapid combustion and those which are heavy and multilayered) is influenced by the oxygen concentration in the chamber. Thus, if the atmosphere inside the chamber becomes oxygen-deficient before the end of the experiment, combustion may cease for some specimens; therefore, it is possible that those layers furthest away from the radiant source will not undergo combustion.

5.5.8.3 The presence of walls causes losses through deposition of combustion particulates.

5.5.8.4 Soot and other solid or liquid combustion products settle on the optical surfaces during a test, resulting in potentially higher smoke density measurements than those due to the smoke in suspension.

5.5.8.5 This test method does not carry out dynamic measurements as smoke simply continues filling a closed chamber; therefore, the smoke obscuration values obtained do not represent conditions of open fires.

6. Apparatus and Ancillary Equipment

6.1 *General*—The apparatus ([Fig. 1](#)) consists of an air-tight test chamber with provision for containing a sample holder, radiation cone, pilot burner, a light transmission and measuring system and other ancillary facilities for controlling the conditions of operation during a test.⁸

6.2 Test Chamber:

6.2.1 Construction:

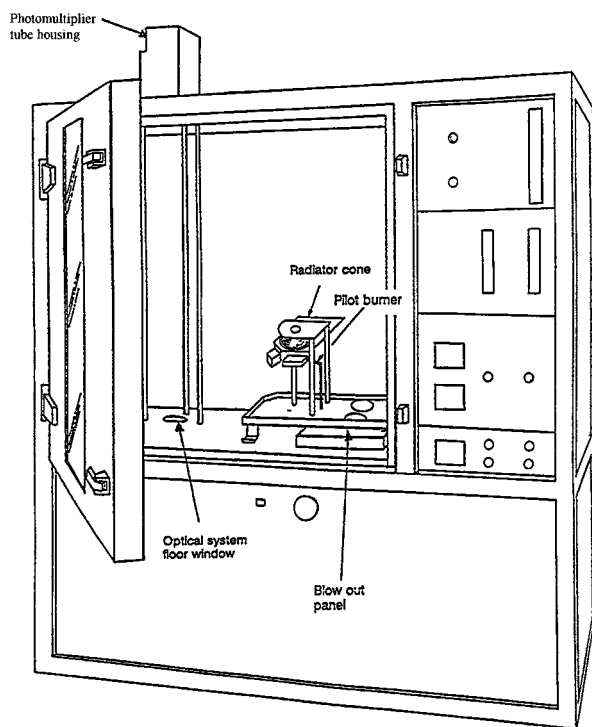
6.2.1.1 Fabricate the test chamber ([Figs. 1 and 2](#)) from laminated panels, the inner surfaces of which shall consist of either a porcelain-enamelled metal, not more than 1 ± 0.1 mm [0.04 ± 0.004 in.] thick, or an equivalent coated metal, which is resistant to chemical attack and corrosion and capable of easy cleaning. The internal dimensions of the chamber shall be 914 ± 3 mm long, 914 ± 3 mm high and 610 ± 3 mm deep [36 ± 0.1 in. by 36 ± 0.1 in. by 24 ± 0.1 in.] ([Fig. 2](#), where the numbers are dimensions, in mm). Provide the chamber with a hinged front-mounted door with an observation window and a removable opaque door cover to the window to prevent light entering the chamber.

6.2.1.2 Fit the chamber with a safety blow-out panel, consisting of a sheet of aluminum foil of thickness not greater

⁶ Some of these limitations are common to many small scale fire-test-response methods.

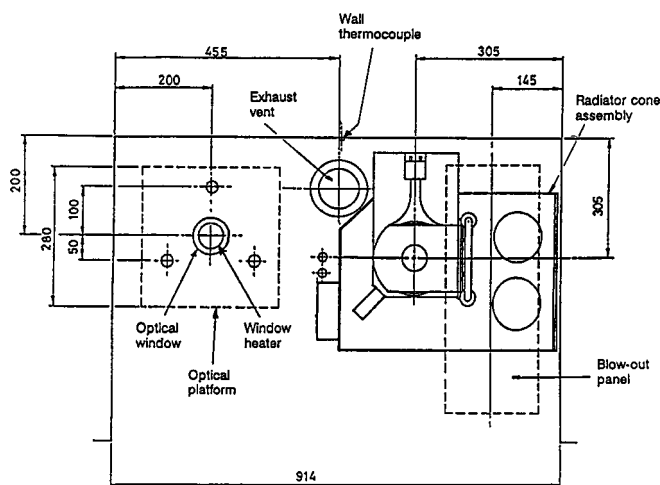
⁷ The boldface numbers in parentheses refer to the list of references at the end of this standard.

⁸ A list of suppliers for such equipment is available from ASTM Headquarters.



NOTE 1—All dimensions given in this figure are in mm unless stated otherwise.

FIG. 1 Typical Arrangement of Test Chamber



NOTE 1—All dimensions in this figure are given in mm unless stated otherwise.

FIG. 2 Plan View of Typical Test Chamber

than 0.04 mm [1.6×10^{-3} in.] and having a minimum area of 80 600 mm² [125 in.²], fastened in such a way as to provide an airtight seal. Figs. 1 and 2 show the blow-out panel location.⁹

6.2.1.3 Mount two optical windows, each with a diameter of 75 ± 1 mm [3 ± 0.04 in.], one each in the top and bottom of the cabinet, at the position shown in Fig. 2, with their interior

faces flush with the outside of the cabinet lining. Provide the underside of the window on the floor with an electric heater of 9 ± 1 W capacity, in the form of a ring, which shall be capable of maintaining the upper surface of the window at a temperature just sufficient to minimize smoke condensation on that face.¹⁰ Mount the heater around the window edge so as not to interrupt the light path (Fig. 2).

6.2.1.4 Mount optical platforms, 8 ± 0.1 mm [0.31 ± 0.004 in.] thick, around the windows on the outside of the chamber and hold them rigidly in position relative to each other by three metal rods, with a diameter of at least 12.5 mm [0.5 in.], extending through the chamber and fastened securely to the platforms.

6.2.1.5 Provide other openings in the cabinet for services, as specified. They shall be capable of being closed so as to develop a positive pressure of up to 1.5-kPa (150-mm water gage) above atmospheric pressure inside the chamber (see 6.2.2) and maintained when checked in accordance with 6.6 and 9.6. All components of the chamber shall be capable of withstanding a greater internal positive pressure than the safety blow-out panel.

6.2.1.6 Provide an inlet vent with shutter in the front of the chamber at the top and away from the radiator cone. Also, provide an exhaust vent with shutter in the bottom of the chamber to lead, via flexible pipe with a diameter of 50 to 100 mm [2 to 4 in.], to an extraction fan capable of creating a negative pressure of at least 0.5-kPa (50-mm water gage).

6.2.2 *Chamber Pressure Control Facilities*—Provision shall be made for controlling the pressure inside the test chamber. A water manometer, with a range of up to 1.5-kPa (150-mm water gage) shall be provided for connection to a pressure regulator and to a tube in the top of the chamber.¹¹

6.2.3 *Chamber Temperature*—A thermocouple junction, made from wires of diameter not greater than 1 mm [0.04 in.], shall be mounted on the inside of the back wall of the chamber, at the geometric center, by means of an insulating disc, such as polystyrene foam, with a thickness of 6.5 ± 0.2 mm [0.25 in.] and a diameter of not more than 20 mm [0.8 in.] attached with a suitable cement. The thermocouple junction shall be connected to a recorder, meter, or data acquisition unit, and the system shall be suitable for measuring temperatures in the range of 35 to 60 °C [64 to 140 °F] (see 11.1.4).

6.3 Sample Support and Heating Arrangements:

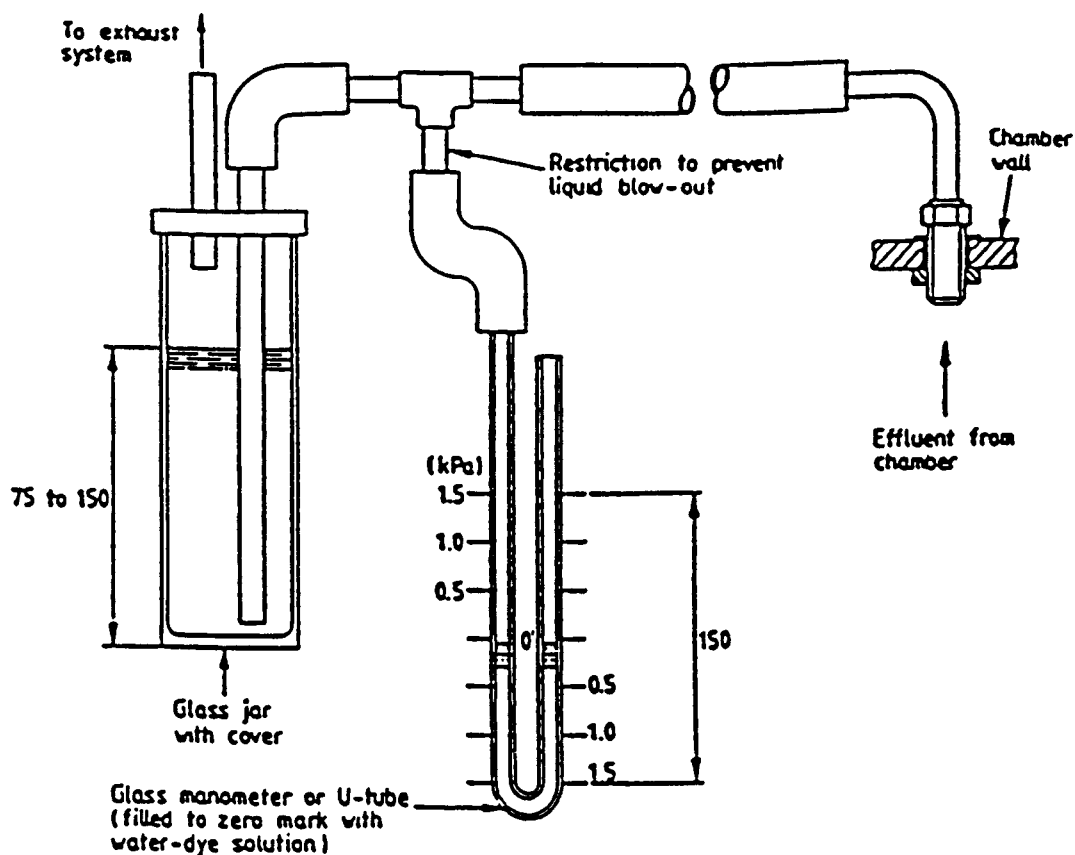
6.3.1 Radiator Cone:

6.3.1.1 The radiator cone (Fig. 4) shall consist of a heating element, of nominal rating 450 W, contained within a stainless steel tube, 2210 ± 5 mm [87 ± 0.2 in.] in length and 6.5 ± 0.2 mm [0.25 ± 0.008 in.] in diameter, coiled into the shape of a truncated cone and fitted into a shade. The shade shall have an overall height of 45 ± 0.04 mm [1.8 ± 0.02 in.], an internal diameter of 55 ± 1 mm [2.2 ± 0.04 in.] and an internal base diameter of 110 ± 3 mm [4.3 ± 0.1 in.]. It shall consist of two

¹⁰ A window temperature of at least 50-55°C [122-131°F] has been found suitable and normally is achieved with a 9W heater.

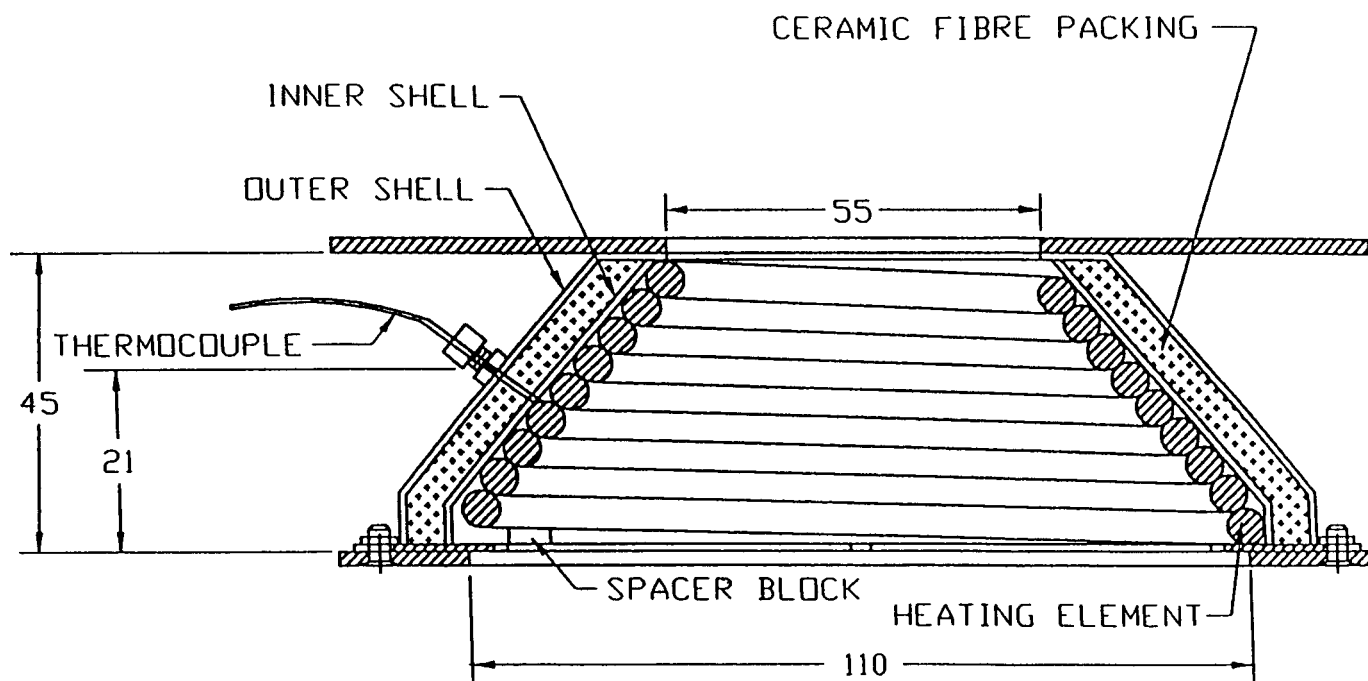
¹¹ A suitable pressure regulator consists of an open water-filled bottle and a length of flexible tubing (Fig. 3), inserted 100 mm [4 in.] below the water surface; the other end of the tubing is connected to the manometer and the chamber. The regulator shall be vented to the exhaust system.

⁹ Stainless steel wire mesh for fastening the aluminum foil, offers adequate protection for the blow-out panel.



NOTE 1—All dimensions in this figure are given in mm unless stated otherwise.

FIG. 3 Typical Chamber Pressure Relief Manometer



NOTE 1—All dimensions in this figure are given in mm unless stated otherwise.

FIG. 4 Cross-sectional View Through the Radiator Cone Heater

layers of 1 ± 0.1 -mm [0.04 ± 0.004 -in.] thick stainless steel with a 10 ± 0.5 -mm [0.4 ± 0.02 -in.] thickness of ceramic fibre

insulation of nominal density 100 kg/m³ [6.2 lb/ft³], sandwiched between them. Clamp the heating element by two plates at the top and bottom of the element (see also [Appendix X1](#)).

6.3.1.2 The radiator cone shall be capable of providing irradiance in the range 10 to 50 kW/m², at the center of the surface of the specimen. The irradiance shall also be determined at a position of 25 ± 2 mm [1 ± 0.08 in.] to each side of the specimen center, and the irradiance at these two positions shall be not less than 85 %, and not more than 115 %, of the irradiance at the center of the specimen.

6.3.1.3 The irradiance of the radiator cone shall be controlled by reference to the averaged reading of two type K thermocouples. The thermocouples shall be 1.6 ± 0.2 mm [0.055 to 0.071 in.] outside diameter, sheathed with an unexposed hot junction, mounted diametrically opposite, in contact with, but not welded to, the heating element, and positioned at one third of the distance from the top surface of the cone. It has been found that thermocouples of equal length and wired in parallel to the temperature controller perform adequately; alternate wiring methods shown to give equivalent results also are acceptable (see also [Appendix X2](#)).¹²

6.3.1.4 The temperature at the heater is to be controlled and shall be held steady to ±2°C [±4°F]. The temperature controller for the radiator cone shall be of the proportional, integral and derivative Type 3-term controller with thyristor stack fast-cycle or phase angle control of not less than 10 A max rating. Capacity for adjustment of integral time between 10s and 50s and differential time between 25s and 30s shall be provided to permit reasonable matching with the response characteristics of the heater. A temperature input range of 0 to 1000°C [32 to 1832°F] is suitable; an irradiance of 50 kW/m² will be given by a heater temperature in the 700 to 750°C [1292 to 1382°F] temperature range. Automatic cold junction compensation of the thermocouple shall be provided. The described design has been shown to be satisfactory; alternate devices shown to give equivalent results are also acceptable.¹³

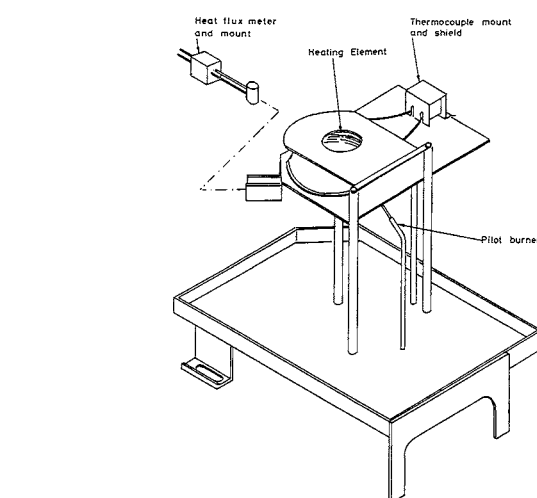
6.3.2 Framework for Support of the Radiator Cone, Specimen Holder, and Heat-Flux Meter:

6.3.2.1 The radiator cone shall be secured from the vertical rods of the support framework and located so that the lower rim of the radiator cone shade is 25 ± 1 mm [1 ± 0.04 in.] above the upper surface of the specimen, when oriented in the horizontal position. Details of the radiator cone and supports are shown in [Figs. 5 and 6](#). The base of the specimen holder contains a height adjustment device to ensure a consistent distance between radiator cone and specimen surface.

6.3.3 **Radiation Shield**—The cone heater shall be provided with a removable radiation shield to protect the specimen from the irradiance prior to the start of the test. The radiation shield shall be made of noncombustible material with a total thickness not to exceed 12 mm. The radiation shield shall comply with

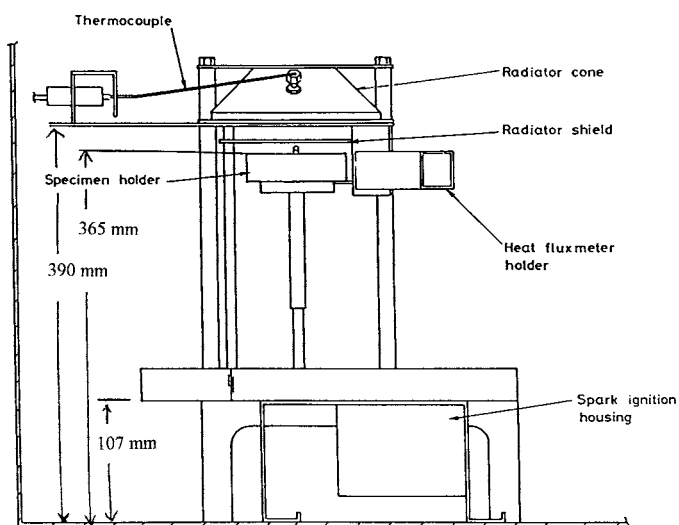
¹² Sheathed chromel/alumel type K thermocouples have been found suitable for this purpose.

¹³ While phase angle control is allowed for the temperature controller of the radiator cone, it must be noted that this usually will require electrical filtering to avoid the risk of inducing noise in low signal level lines.



NOTE 1—All dimensions in this figure are given in mm unless stated otherwise.

FIG. 5 Typical Framework for Support of Radiator Cone, Specimen and Flux Meter



NOTE 1—The dimensions in this figure are given in mm unless stated otherwise.

FIG. 6 Typical Arrangement of Radiator Cone, Specimen Holder and Radiator Shield (Side View)

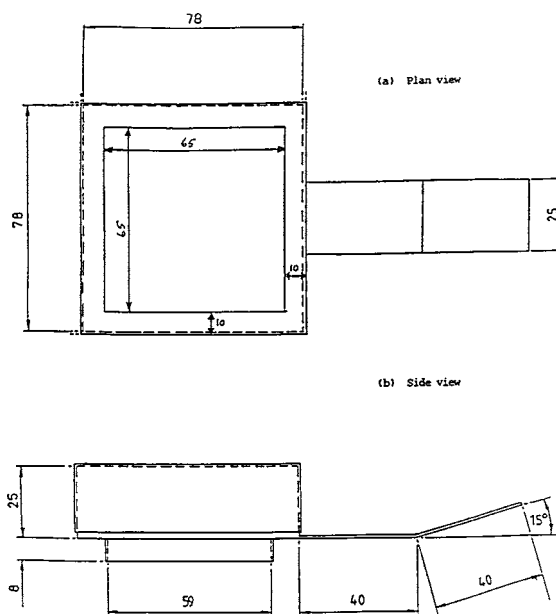
either 6.3.3.1 or 6.3.3.2 and shall be kept in place for a maximum period of 10s.¹⁴

6.3.3.1 A water-cooled radiation shield coated with a durable matte black finish of surface emissivity $e = 0.95 \pm 0.05$; or,

6.3.3.2 A radiation shield with a reflective top surface in order to minimize radiation transfer but not water-cooled.

6.3.3.3 The radiation shield shall be equipped with a handle or other suitable means for quick insertion and removal. The

¹⁴ It is possible that the use of a radiation shield for periods longer than 10s will affect radiator heat control and, consequently, the heat-flux level applied to the specimen.



NOTE 1—The dimensions in this figure are given in mm unless stated otherwise.

FIG. 7 Specimen Holder

cone heater base plate shall be equipped with the means for holding the radiation shield in position and allowing its easy and quick removal.¹⁵

6.3.4 Heat Flux Meter:

6.3.4.1 The heat flux meter shall be of the Schmidt-Boelter (thermopile) type, with a design range of at least 50 kW/m². The sensing surface of the heat flux meter (Fig. 5) shall have a flat, circular face of 10 ± 1-mm [0.4 ± 0.04-in.] diameter, coated with a durable matt black finish. The heat flux meter shall be water-cooled^{16, 17} and shall have an accuracy of ±3 % (see also Appendix X2).

6.3.4.2 The heat flux meter shall be connected directly to a suitable recorder, or data acquisition unit (6.8.6), so that it is capable, when calibrated, of recording heat fluxes of 25 kW/m² and 50 kW/m².¹⁸

6.3.4.3 For calibration of the heat flux meter system, see 9.8.

6.3.5 Specimen Holders:

6.3.5.1 Details of the specimen holder are shown in Fig. 7. The base shall be lined with a low density (nominally 65 kg/m³ [4 lb/ft³]) refractory fibre blanket, with a minimum thickness of 10 mm [0.4 in.].

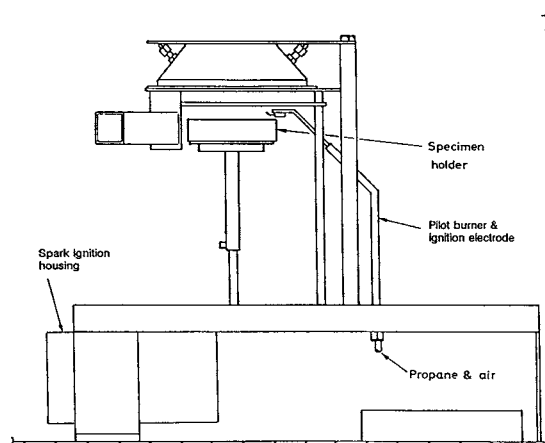
6.3.5.2 A retainer frame and wire grid shall be used for all tests. The wire grid shall be 75 ± 1-mm [3 ± 0.04-in.] square

¹⁵ This device is necessary in order to enable repeat tests to be carried out without switching off the radiator cone.

¹⁶ If the cooling temperature is lower than the temperature at which the gage is calibrated, condensation on the sensor is possible and would lead to serious measurement errors.

¹⁷ The manufacturer of Schmidt-Boelter gages has the following specifications for cooling water: pressure 413–621 kPa, temperature 20.0–26.6°C and flow rate 0.76–1.14 L/min.

¹⁸ If a chart recorder which only displays a millivolt output is used, the millivolt value shall be converted to heat flux, in kW/m², using the calibration factor (or equation, if appropriate) specific to the heat flux meter.



NOTE 1—The dimensions in this figure are given in mm unless stated otherwise.

FIG. 8 Typical Arrangement of Radiator Cone, Specimen Holder and Radiator Shield (Front View)

with 20 ± 0.5 mm [0.8 ± 0.02 in.] square holes constructed from 2 ± 0.2 mm [0.08 ± 0.008 in.] stainless steel rod, welded at all intersections.¹⁹

6.3.6 Pilot Burner:

6.3.6.1 The flame from the single-flame burner, Fig. 8, shall have a length of 30 ± 5 mm [1.2 ± 0.2 in.] and shall be positioned horizontally 10 ± 1 mm [0.4 ± 0.04 in.] above the top face of the specimen. The color of the flame shall be blue, with a yellow tip. Ensure that the tip of the burner is aligned with the edge of the specimen, as shown in Fig. 9.

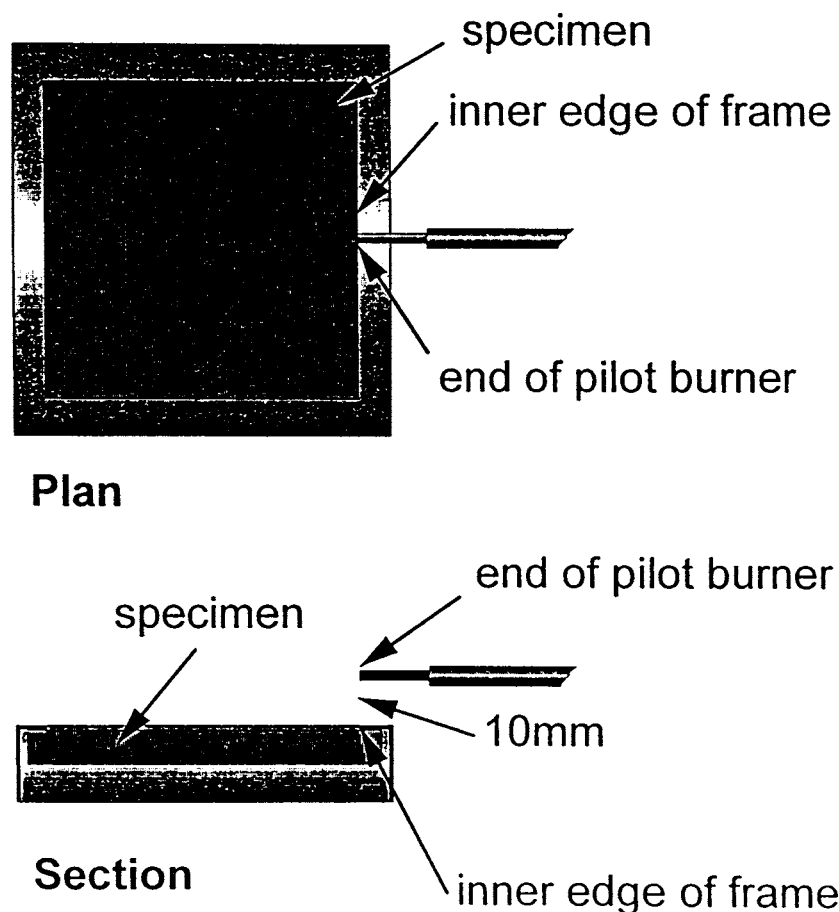
6.3.6.2 Install a small spark ignition device, sited next to the outlet tube of the burner, for the operator to cause reignition of the flame without opening the door of the chamber. A suitable system is a spark plug with a 3-mm [0.11-in.] gap, powered from a 10-kV transformer. A suitable transformer is of a type specifically designed for spark-ignition use, with an isolated (ungrounded) secondary to minimize interference with the data-transmission lines. An acceptable electrode length and spark plug location is such that the spark gap is located 13 mm [0.5 in.] above the specimen, close to the pilot burner.

6.4 Gas Supply:

6.4.1 A mixture of propane, of at least 95 % purity and at a pressure of 3.5 ± 1-kPa (350 ± 100-mm water gage), and air at a pressure of 170 ± 30-kPa (17 ± 3-m water gage) shall be supplied to the burner. Each gas shall be fed to a point at which they are mixed and supplied to the burner.

6.4.2 The use of needle valves and calibrated flowmeters is a suitable method of controlling gas flows. The flowmeter for the propane supply shall be capable of measuring 50 cm³/min [18 × 10⁻⁴ ft³/min] flow rates and that for air a value of 500

¹⁹ The retainer frame and wire grid particularly are appropriate when testing intumescent specimens and also for reducing unrepresentative edge combustion of composite samples or for retaining specimens prone to delamination. The wire grid is likely to affect the test results, compared to tests conducted in its absence; however, its use is recommended for several reasons: it helps to promote uniformity in testing by different laboratories, in view of the expected effect of the retainer frame and wire grid on test results, it is needed for certain specimens, as explained above, and it is required in ISO 5659–2.



NOTE 1—The dimensions in this figure are given in mm unless stated otherwise.

FIG. 9 Detailed Location of Pilot Burner

cm³/min [18×10^{-3} ft³/min]. Alternate devices shown to give equivalent results are also acceptable.

6.5 Photometric System:

6.5.1 General:

6.5.1.1 The photometric system shall consist of a light source and lens in a light-tight housing mounted below the optical window in the floor of the cabinet, and a photo-detector with lens, filters and shutter in a light-tight housing above the optical window in the top of the chamber.

6.5.1.2 The system shall be as shown in Fig. 10. Equipment shall be provided to control the output of the light source and to measure the amount of light falling on the photo-detector.

6.5.2 Light Source:

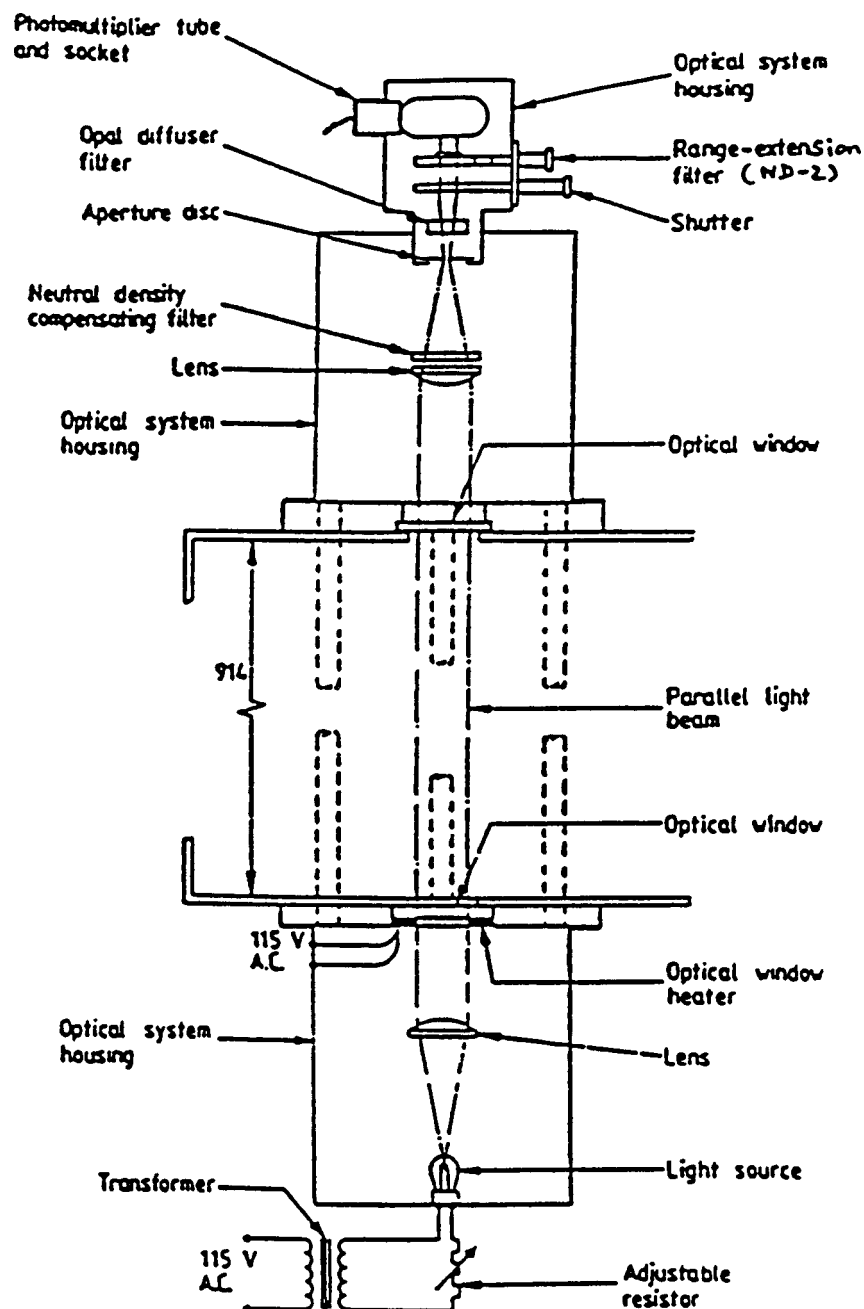
6.5.2.1 The light source shall be a 6.5 V incandescent lamp. Power for the lamp shall be provided by a transformer producing 6.5 V and a rheostat so that the r.m.s. voltage across the lamp, as determined by a voltmeter, is maintained at 4 ± 0.2 V. The lamp shall be mounted in the lower light-tight box, and a lens to provide a collimated light beam of 51-mm [2-in.] diameter, passing towards and through the optical window on the floor of the chamber, shall be mounted, with provision for adjustment, to control the collimated beam in direction and diameter. The housing shall be provided with a cover to allow access for adjustments to be made to the position of the lens.

6.5.3 Photo-Detector:

6.5.3.1 The light-measuring device system shall consist of a photo-multiplier tube connected to a multirange amplifier coupled to a recording device, or data acquisition unit (6.8.6), capable of measuring continuously relative light intensity against time as percentage transmission over at least five orders of magnitude, with an S-4 spectral sensitivity response similar to that of human vision and a dark current less than 10^{-9} A. The system shall have a linear response with respect to transmittance and an accuracy of better than $\pm 3\%$ of the maximum reading on any range. For selection of photomultiplier tubes, as applicable, the minimum sensitivity shall allow a 100 % reading to be obtained with a 0.5 neutral density filter and an ND-2 range extension filter (see 6.5.3.2) in the light path. Provision shall be made for adjusting the reading of the instrument under given conditions over the full range of any scale.²⁰

6.5.3.2 The photo-multiplier tube shall be mounted in the upper section of the detector housing. Below it, there shall be an assembly which provides for the rapid positioning of a filter and of a shutter, in or out of the path of the collimated light

²⁰ The required accuracy of the photo-detector is obtained more easily if the measuring systems incorporate scale ranges of 30, 3, 0.3, etc., as well as ranges of 100, 10, 1, etc.



NOTE 1—The dimensions in this figure are given in mm unless stated otherwise.

FIG. 10 Photometric System

beam, each being operated separately. The filter, referred to as the range-extension filter (ND-2), shall be a glass neutral density filter of nominal optical density 2. When in the closed position, the shutter shall prevent all light in the test chamber from reaching the photo-multiplier tube. An opal diffuser shall be mounted permanently below the shutter.

6.5.3.3 The lower part of the housing shall support a $51 \pm 1\text{-mm}$ [$2 \pm 0.04\text{-in.}$] diameter lens, capable of being adjusted

so that the collimated beam is focused to form a small intense spot of light at the disc aperture between the upper and lower parts of the housing. Above the lens, there shall be a mount for supporting one or more compensating filters from a set of nine gelatin neutral density filters, with optical density varying from 0.1 to 0.9 in steps of 0.1. The housing shall be provided with a cover, to allow access for adjustments to be made to the position of the lens and for inserting or removing filters.

6.5.3.4 A neutral density filter, with a nominal optical density of 3.0, large enough to cover the lower optical window, the actual optical density having been determined by calibration, shall be available for calibrating the photometric system.²¹

6.5.4 Additional Equipment:

6.5.4.1 A template for checking the collimated light beam shall consist of an opaque disc marked with a concentric ring of $51 \pm 1\text{-mm}$ [$2 \pm 0.04\text{-in.}$] diameter, shall be capable of fitting snugly between the support pillars. It shall be capable of being attached to, and centered on, the underside of the upper optical window in the chamber.

6.5.4.2 A piece of white cloth, paper tissue or a neutral density filter of sufficient size to cover completely the lower optical window of the chamber and capable of transmitting a sufficient amount of light to give a midscale reading of the photometric system when switched to the scale with a range of 1 % transmission, shall be available for calibrating the range-extender filter.

6.5.4.3 A piece of opaque material, sufficiently large to cover the lower optical window, shall be available for blocking the light from the light source entering the chamber.

6.6 *Chamber Leakage*—With the specified items of equipment assembled properly and ready for test, the chamber shall be sufficiently air-tight to comply with the requirements of the leakage rate test given in 9.6.²²

6.7 *Cleaning Materials*—Conduct periodic cleaning to ensure proper operation (see also 11.1.2). Have available appropriate materials for cleaning the inside of the chamber. The optical system windows, viewing window, chamber walls, and specimen holders must all be cleaned regularly. A recommended cleaning procedure is presented in 6.7.1-6.7.4.

6.7.1 *Optical System Windows Recommended Procedure*—Clean the exposed surfaces of the glass separating the photo-detector and light source housings from the interior of the chamber after each test. Clean the top window first, then the bottom window, using a nonabrasive cloth dampened with a suitable cleaner.²³ Dry the window to prevent streaking or film buildup. Do not use any cleaners that contain wax because wax will cause the smoke to adsorb to the glass more quickly.

6.7.2 *Viewing Window*—Clean the viewing window periodically, as required, to allow viewing the chamber interior during testing.²¹

6.7.3 *Chamber Walls*—Clean the chamber walls periodically to prevent excessive build-up of smoke products. An ammoniated spray detergent and soft scouring pads have been found effective for cleaning the chamber walls.

6.7.4 *Specimen Holders*—Remove any charred residues on the specimen holders and horizontal rods securing the holder position to prevent contamination of subsequent specimens.

6.8 Ancillary Equipment:

6.8.1 *Balance*—Use a balance with a capacity exceeding the mass of the specimen and which shall be readable and accurate to 0.5 % of the specimen mass.

6.8.2 *Timing Device*—Use a timing device capable of recording elapsed time to the nearest second, over a period of at least 1 hour, with an accuracy of 1s in 1 hour, for timing operations and observations.

6.8.3 *Linear Measuring Devices*—Use rules, calipers, gages, or other devices of suitable accuracy, for checking all dimensions specified with given tolerances.

6.8.4 *Auxiliary Heater*—Use an auxiliary heater of 500 W capacity, capable of raising the air temperature uniformly without local heating of the walls, if required, to help the chamber to reach the stabilized temperature more rapidly under adverse conditions.

6.8.5 *Protective Equipment*—Protective clothing, such as gloves, goggles, respirators, and handling equipment, such as tongs, always shall be available and shall be used when the type of sample being tested demands them (see Section 7).

6.8.6 *Data Acquisition*—Use a recorder, or a data acquisition unit, capable of continuously recording the millivolt output of the photo-detector (6.5.3) to an accuracy of better than 0.5 % of full-range deflection. The device used also shall be capable of recording the heat-flux meter output (see 6.3.4.2) to the required accuracy. If a data acquisition unit is used, the data collection intervals shall be 5s or less. If a recorder is used, the recording chart drive shall be used at a minimum chart speed of 10 mm/min [0.4 in./min].

6.8.7 *Thermometer*—Use a thermometer, or a Type K thermocouple, capable of measuring temperature over the range 20 to 100 °C [68 to 212 °F], to an accuracy of ± 0.5 °C [± 0.9 °F], for determining ambient temperature or any other needed temperature.

6.8.8 *Water Circulating Device*—Use a device for water circulation to cool the heat-flux meter.

6.9 Test Environment:

6.9.1 Protect the test apparatus from direct sunlight or any strong light source to avoid the possibility of spurious light readings.

6.9.2 Make adequate provision for removing potentially hazardous and objectionable smoke and gases from the area of operation. Also, take suitable precautions to prevent exposure of the operator to such gases, particularly during the removal of specimens from the chamber or when cleaning the apparatus.

7. Operator Safety

7.1 **Warning**—This test procedure involves high temperatures and combustion processes; therefore, it is possible for eye injuries, burns, ignition of extraneous objects, and inhalation of smoke or combustion products to occur, unless proper precautions are taken. To avoid accidental leakage of toxic combustion products into the surrounding atmosphere, it is advisable to evacuate the chamber, at the end of a test, into an exhaust system with adequate capacity. The operator must use heavy gloves, safety tongs, or other suitable protection for removal of the specimen holder. The venting must be checked periodically for proper operation.

²¹ Handle all filters by their edges, because fingerprints greatly affect their rating. Do not attempt to clean the surface of a filter; once the surface has been damaged replace the filter.

²² The most likely sources of leakage have been found to be the door seal, the inlet and outlet vents and the safety blow-out panel.

²³ Ethyl alcohol, ethyl ketone, or equivalent, and soft tissue have been found effective for cleaning the optical windows and the viewing window.

8. Test Specimen

8.1 *Suitability of Sample for Testing:*

8.1.1 The method is suitable for essentially flat specimens only (see 3.2.3).

8.1.2 The results of this test method are sensitive to variations in surface characteristics, thickness of individual layers, overall thickness, mass, and composition.

8.1.3 When preparing replicate specimens for testing, take precautions to ensure all specimens fall within the requirements in 8.6. Keep individual records of the mass of each specimen together with the individual test data of that specimen.

8.2 If the top and bottom faces of samples submitted for evaluation by this test method are different from one another, evaluate both faces if it is possible that each face will be exposed to fire when in use.

8.3 A minimum of six specimens shall be tested so that three specimens are tested at each one of the two required conditions. Unless specified otherwise by the test requester, the standard exposure conditions are flaming at an irradiance of 25 kW/m², and flaming at an irradiance of 50 kW/m².

NOTE 1—Optional testing modes include nonflaming, at an irradiance of 25 kW/m² (needed if comparison is required with the test results from Test Method E 662), and nonflaming, at an irradiance of 50 kW/m² (needed if comparison is required with the test results from ISO 5659-2). These additional exposures are not mandatory (see also X1.4.9). Other testing modes are also possible with this equipment.

8.4 An additional number of specimens, as specified in 8.3, shall be used for each face in accordance with the requirements of 8.2.

8.5 An additional nine specimens (three specimens per mode to be tested) shall be held in reserve, in case they are required by the conditions specified in 11.9.2

8.6 *Size of Specimens:*

8.6.1 The specimens shall be square, with sides 75 ± 1 mm [3 ± 0.04 in.].

8.6.2 Whenever possible, test samples in their end-use thickness. If the end-use thickness is 25 mm [1 in.] or less, test the samples at their full end-use thickness. It is recommended that materials for which end-use thickness is not available be tested at a thickness of 1.0 ± 0.1 mm [0.04 ± 0.004 in.], unless otherwise specified in the material or performance standard or specification.

8.6.3 Samples with a thickness greater than 25 mm [1 in.] shall be cut to give a specimen thickness of 25 ± 1 mm [1 ± 0.04 in.], in such a way that the original (uncut) face is evaluated.

8.6.4 Samples of multilayer materials, products, or assemblies, with a thickness greater than 25 mm [1 in.], consisting of core material(s) with facings of different materials shall be prepared in accordance with 8.6.3, by cutting from the layers behind the facing one (see also 8.7.2).

8.7 *Specimen Preparation:*

8.7.1 The specimen shall be representative of the material, product, or assembly, and shall be prepared in accordance with the procedures described in 8.7.2 and 8.7.3. The specimens shall be cut, sawn, molded or stamped from identical sample

areas of the material, product, or assembly, and records shall be kept of their thicknesses and, if required, their masses.

8.7.2 If the test specimens used are flat representations of the same thickness and composition, of the actual parts, which are not flat, this shall be stated in the test report. Any substrate or core materials for the specimens shall be the same as those used in practice.

8.7.3 When coatings, including paints and adhesives, are tested with the substrate or core as used in practice, specimens shall be prepared following normal practice and in such cases the method of application of the coating, number of coats, and type of substrate shall be included in the test report.

8.8 *Wrapping of Specimens:*

8.8.1 All specimens shall be covered across the back, along the edges, and over the front surface periphery leaving a central exposed specimen area of 65 ± 5 mm by 65 ± 5 mm [2.5 ± 0.2 in. by 2.5 ± 0.2 in.], with a single sheet of aluminum foil (0.04 ± 0.005 mm [0.0016 ± 0.0002 in.] thick) with the dull side in contact with the specimen. Take care not to puncture the foil or to introduce unnecessary wrinkles during the wrapping operation. Fold the foil so as to minimize losses of any molten material at the bottom of the holder. After mounting the specimen into its holder, trim off any excess foil along the front edges, as appropriate.

8.8.2 Back all wrapped specimens with one or more sheets of noncombustible insulating board of an oven dry density of 850 ± 100 kg/m³ [53 ± 6 lb/ft³] and a nominal thickness of 12.5 mm [0.5 in.] to ensure that the top edges of the specimen are pressed against the retaining lips of the specimen holder. Back wrapped specimens less than 25 mm [1 in.] thick with at least one sheet of noncombustible board with or without a layer of mineral fibre blanket underneath to accommodate a wider variety of specimen thicknesses.

8.8.3 In the case of resilient materials, products, or assemblies, install each specimen in its aluminum foil wrapper, in the holder in such a way that the exposed surface lies flush with the inside face of the opening of the specimen holder. Ensure that specimens with uneven exposed surfaces do not protrude beyond the plane of the opening of the specimen holder.

8.8.4 When thin impermeable specimens, such as thermoplastic films, swell during the test due to gases trapped between the film and the backing, they shall be maintained essentially flat by making two or three cuts (20 to 40 mm [0.8 to 1.6 in.] long) in the film to act as vents.

9. Set-up, Calibration, and Maintenance

9.1 *Set-up and Calibration Procedures*—Assemble the apparatus, connect to the services and control devices as specified in Section 6, and check for the proper functioning of the various systems, including the electrical connections to ensure good electrical contact.²⁴

9.2 *Alignment of Photometric System:*

9.2.1 *General*—Conduct the procedure detailed in 9.2.2 and 9.2.3 in the initial setting-up of the apparatus, after the

²⁴ Heat up the radiator cone gradually from cold, and do not allow it to overheat or to remain operating without a blank specimen holder, a holder with a specimen in it or the heat-flux meter in position in front of it.

replacement of the light source or after some accidental misalignment has occurred, and then always follow this by the procedure for selecting the appropriate compensating filter(s) (see 9.3).

9.2.2 *Beam Collimation:*

9.2.2.1 Check the optical platforms for rigidity. Attach the opaque-disc template (see 6.5.4.1) to the lower face of the upper optical window with the marked ring downwards and centered on the window. Switch on the light source and adjust its projected image on the template so that the light beam completely fills the 51-mm [2-in.] diameter ring with no more light outside the ring than is necessary to satisfy this requirement.

9.2.2.2 Make the adjustments by removing the cover to the light-source enclosure, releasing the lower lens mount fixings and repositioning the lens mount so that the light pattern on the template is centered and of the correct size. If these adjustments are insufficient for proper alignment, reposition the lamp socket also.

9.2.2.3 Refix the lens mount and replace the cover ensuring that the test cabinet has been adequately resealed. Remove the template from the upper optical window.²⁵

9.2.3 *Beam Focusing*—Open the cover to the housing on top of the test chamber, remove the compensating filter holder, and slacken the lens mount. With the photo-detector system switched off and the light source switched on, adjust the lens mount for focusing and alignment so that the converging beam forms a small intense spot of light on the aperture to the photomultiplier tube housing. Tighten the lens mount, check the beam focusing adjustment, replace the compensating filter holder, close and seal the enclosure cover.

9.3 *Selection of Compensating Filter(s)*—Clean the faces of both optical windows inside the test chamber. Switch on the photometric system with the range extension filter in the light path, the shutter open, and the multi-range meter set to the range capable of recording 100 % light transmission. Operate the control for adjusting the reading of the instrument to determine whether a reading of 100 % is achievable. If it is, no change in compensating filter is required; if not, use another compensating filter to satisfy this requirement.²⁶

9.4 *Linearity Check:*

9.4.1 Switch on the photometric system with the range extension filter in the light path and the shutter closed. Adjust the zeroing device to give a reading of 0 % transmission with the instrument range switched to a full-scale reading of 100 % transmission; switch the instrument to the other ranges to determine that the recorded transmission remains 0 %.

9.4.2 Place the calibrated filter, with a nominal optical density of 3.0, in the light path over the lower optical window,

²⁵ On occasions, this adjustment also includes the optimization of the lens mount position so that the reading given by the photo-detector is a maximum; this operation will require removal of the template and shall be followed by a final check on the position of the image as described above.

²⁶ An indication of the appropriate filter, or combination of filters, is obtained conveniently by removing any compensating filter in the housing above the test chamber, closing the housing cover, placing a compensating filter, or filters, over the lower optical window inside the test chamber and checking the instrument reading. The choice of compensating filter determined this way must be confirmed by the specified procedure.

TABLE 1 Frequency of Checks and Calibrations

Item of equipment	Maximum interval between checks and calibrations	Procedure (section reference)
Test chamber interior	Inspect before testing every specimen and before any calibration	9.10
Radiator cone	Once every test day and when renewed or replaced	9.9
Chamber leakage rate	Once every test day and when new seals or safety blow-out panel are fitted	9.6
Heat-flux meter	Every three months and when cleaned or recoated	9.8 and Annex A
Photometric system:		
Calibration	Before testing every specimen	11.3
Alignment	Every six months and when light source is replaced or when damage is incurred	9.2
Compensating filters	Every six months and when transmission through windows deteriorates	9.3
Linearity	Every six months and when transmission through windows deteriorates	9.4
Range-extension filter	Every six months	9.5
Total system	Every month or after the system has been used for more than 100 tests	9.12

open the shutter and measure the percentage transmission. The difference between the observed reading and the calibrated value, when expressed as a percentage of the average of the two values, shall be within 5 %.

9.5 *Calibration of Range-Extension Filter:*

9.5.1 Bring the apparatus to its normal operating condition (see 11.1) with the chamber wall temperature remaining steady at 40 ± 5 °C. Switch on the photometric system with the range-extension filter in the light path and with the shutter open, switch the amplifier to its 100 % transmission range. Place the white cloth, sheets of tissue or filter with an optical density of about 2.5 (see 6.5.3) over the lower optical window, and switch to the 1 % transmission range. Set the reading to 0.50 % by adjusting the instrument. Without disturbing the cloth, tissue or filter, reset to the 100 % transmission and withdraw the range-extension filter (ND-2) from the light path. Record the transmission reading (Ts) and use it to determine, from Table 1²⁷, the value of the appropriate correction factor (Cf) for readings obtained when the range extension filter is not in the light path.

9.5.2 For materials, products, or assemblies having known performance, this calibration procedure is not needed unless the optical density is greater than three.

9.6 *Chamber Leakage Rate Test*—Measure the air-tightness of the test chamber on each occasion of use (with the door, vents and spare gas sampling pipes closed) by introducing compressed air into the test chamber through one of the gas

²⁷ Note that the values in Table 2 have been corrected and are different from those in Test Method E 662, which are inaccurate.

sampling pipes (or other compressed air inlet) until the pressure recorded on the manometer is over 0.76 kPa (76-mm water gage) and then shutting the supply off. The air-tightness of the test chamber shall be such that the time taken for the recorded pressure to drop from 0.76 to 0.50-kPa (76 to 50-mm water gage), determined using the timing device, shall be not less than 5.0 min.

9.7 Burner Calibration—Set the propane flow to 88.5 ± 1.0 cm³/min [0.003 ± 0.00003 ft³/min] and the air flow to 270 $\pm$ 20 cm³/min [0.01 ± 0.0007 ft³/min] (see 6.4).

9.8 Heat-Flux Meter—Calibrate the heat-flux meter system by comparing its response with that of a primary reference standard, when exposed to irradiances of 25 and 50 kW/m² $\pm$ 1 kW/m², averaged over the 10 $\pm$ 1-mm [0.4 ± 0.04 -in.] diameter area of the heat-flux meter (see also 6.3.3 and Annex A2).

9.9 Radiator Cone Calibration:

9.9.1 Clean the apparatus of any residues left from previous tests, and, when a cone calibration is to follow soon after a test, flush the chamber (with the door shut and the exhaust and inlet vents open) with air for 2 min. Mount the heat-flux meter, as specified in 6.3.2.

9.9.2 Mount the heat-flux meter (see 6.3.2) and connect to the electrical and water services.

9.9.3 Do not ignite the burner during this calibration. Bring the apparatus to its normal operation condition (see 11.1) with the chamber wall temperature remaining steady (see 11.1.4) and move the radiation shield away from the cone.

9.9.4 With the chamber door closed, the inlet vent open and the exhaust vent closed, supply water to the heat-flux meter to cool the heat-flux meter body. Monitor the heat flux meter output to determine when thermal equilibrium has been reached, and then adjust the cone, as necessary, to give a steady millivolt reading corresponding to the calibrated value equivalent to an irradiance of 25 kW/m², or 50 kW/m², as required. If the door is opened for any reason during calibration, allow sufficient time after closing the door for thermal equilibrium to be reached before taking the final millivolt reading.^{28,29}

9.9.5 Repeat the procedure of 9.9.3 as necessary to calibrate the equipment in three positions, that is, at the center and at 25 $\pm$ 1 mm [1 ± 0.04 in.] each side of the center.

9.9.6 Return the radiation shield to the position below the cone and remove the heat flux meter from the test chamber so that tests on specimens can proceed immediately.³⁰

9.10 Cleaning—Clean the inside walls of the chamber and the supporting framework for the cone and specimen holders using materials as described in 6.7, whenever periodic visual inspection indicates the need (see also 11.1.2).

9.11 Frequency of Checking and Calibrating Procedures:

9.11.1 Undertake regular checking and calibration at periods as given in Table 1.³¹

9.11.2 Follow the relevant setting up procedure after any part of the equipment has been renewed or repaired.

9.12 Total System—Check the total system by testing a material, or product with repeatable results, and which is, and is likely to continue to be, consistently available to the testing laboratory. Maintain a record of the test results obtained. If erratic values are observed, identify and correct any instrumental or operational deficiencies.

10. Conditioning

10.1 Prior to testing, condition the specimens to constant mass in an atmosphere at a temperature of 23 $\pm$ 3 °C [73 ± 5 °F] and a relative humidity of 50 $\pm$ 10 %. Constant mass shall be considered to have been reached when two successive weighing operations, carried out at an interval of 24 h, do not differ by more than 0.1 % of the mass of the test piece, or 0.1 g, whichever is the greater. Test the specimen within 10 min of removal from the conditioning atmosphere, if the test room conditions differ from the above.

10.2 Forced-air movement in the conditioning chamber is acceptable to assist in accelerating the conditioning process.

10.3 While in the conditioning chamber, support specimens in racks so that air has access to all surfaces.

11. Test Procedure

11.1 Initial Conditions:

11.1.1 Record the mass of each test specimen, wrapped in aluminum foil, before placing it inside the specimen holder, to generate an initial mass (m_i) (in g).

11.1.2 Before starting a test, ensure that all internal chamber surfaces are clean and free of accumulated residues.³²

11.1.3 Prepare the test chamber in accordance with the requirements of Section 9, with the radiator cone set at an irradiance of 25 kW/m² or of 50 kW/m².

11.1.4 If a test has just been completed, flush the test chamber with air until it is completely clear of smoke, with the test chamber door closed and the exhaust and inlet vents open. Inspect the inside of the cabinet and clean the walls and the supporting framework wherever necessary (see 9.9). Clean the faces of the optical windows inside the chamber before each test. Allow the apparatus to stabilize until the chamber wall temperature is within the range 40 $\pm$ 5 °C [104 ± 9 °F] for tests with the radiator cone at 25 kW/m², or within the range 55

²⁸ With some water circulators, it is necessary to have the chamber door slightly open to allow access for the tubing.

²⁹ Allow at least 10 min for stabilizing between adjustments.

³⁰ It is necessary to continue to circulate water through the heat-flux meter until the meter is cool enough for the protective cap to be replaced without melting or distortion.

³¹ Combustion products of some materials, products, or assemblies may cause corrosion of the cone heating element which may be compensated for by adjusting the applied voltage for a limited amount of change. If the cone cannot be made to give the required output, a new heating element may be required.

³² Sensitivity to variations requires that, when changing to another specimen to be tested, it is first necessary to clean and remove from the walls all accumulated residues, to ensure that chemical or physical recombination with the effluents or residues produced as a result of the thermal irradiance does not affect the data obtained. Even when testing the same specimen, excessive accumulations of residue shall not be permitted to build up, since ruggedness tests have indicated that such deposits serve as additional insulators, tending to reduce normally expected condensation of the aerosol, thereby raising the measured specific optical density.

$\pm 5\text{ }^{\circ}\text{C}$ [$131 \pm 9\text{ }^{\circ}\text{F}$] for tests with the radiator cone at 50 kW/m^2 . Close the inlet valve.³³

11.2 Tests With Pilot Flame—Place the pilot flame burner in its correct position (Fig. 9), turn on the gas and air supplies, and ignite the burner. Then, check the flow rates, and, if necessary, adjust the flow rates to ensure that they are as determined by the setting up procedure described in 9.7.

11.3 Preparation of Photometric System—Set the zero and then open the shutter to set the full scale 100 % transmission reading. Close the shutters again and check and reset the zero, if necessary, using the most sensitive 0.1 % range. Recheck the 100 % setting. Repeat the sequence of operations until accurate zero and 100 % readings are obtained on the amplifier and recorder, or data acquisition unit, when the shutters are opened and closed.

11.4 Loading Specimen:

11.4.1 Put the radiation shield in position. Place a wrapped specimen, prepared in accordance with 8.3 and 8.4 with its backing board, in its holder. Place the holder and specimen on the supporting framework below the radiator cone and immediately close the test chamber door. The radiation shield shall be in position for no longer than 10s (see 6.3.3).

11.4.2 Start the test by removing the radiation shield from below the cone. Then, simultaneously start the recording chart drive or data acquisition unit and close the inlet vent.

11.4.3 If preliminary tests indicate that the pilot flame is extinguished before the radiation shield is removed, this problem shall be addressed before continuing with the test, for example by using the spark igniter (see 6.3.6.2).

11.4.4 If the pilot flame is extinguished by gaseous effluent during a test and fails to reignite within 10s, switch off the gas supply to the pilot burner and mark the test as invalid.

11.5 Recording of Light Transmission:

11.5.1 Record the percentage light transmission and the corresponding time continuously from the start of the test, which corresponds to the time when the radiation shield was removed. Switch the range of the photo-detector amplifier system to the next decade when required, so that readings less than 10 % of full-scale deflection are avoided.

11.5.2 If the light transmission falls below 0.01 %, cover the observation window in the chamber door and withdraw the range-extension filter from the light path.

11.6 Observations:

11.6.1 Record the time at which a flame is present on the specimen surface, if it occurs.

11.6.2 Record any particular burning characteristics of the specimens, such as delamination, intumescence, shrinkage, melting, dripping, collapse, occurrence of pool fire under the test specimen, or any other event of special interest, and record the time at which the particular behavior occurs, including the time to ignition and duration of flaming. Also, record the smoke characteristics, such as color, and the nature of the settled particulate matter. All times are reported from the moment the test is started (see 11.4.2).

11.7 Termination of Test:

11.7.1 Conduct the test for a period of 10 min. It is permissible to conduct this test for periods in excess of 10 min, when minimum light transmittance values have not been reached during a 10 min exposure. If the period exceeds 10 min, report the test time.

11.7.2 Extinguish the burner if the pilot flame has been used.³⁴

11.7.3 Reposition the radiation shield below the cone.

11.7.4 Switch on the exhaust fan, and when the water manometer indicates a small negative pressure, open the inlet vent and continue exhausting until a maximum value of light transmission is recorded, with the appropriate range selected, and noted as the “clear beam” reading, T_c , for use in correcting for deposits on the optical windows.

11.8 Specimen Mass—At the conclusion of each test, determine the final specimen mass (m_f) (in g), after removal from the specimen holder. Include the aluminum foil in which the specimen had been wrapped during the test for determining the mass.

11.9 Repeat Tests:

11.9.1 Measure the percentage light transmission of two sets of three specimens for each sample, one set for each mode from among the standard exposure conditions shown below. Unless specified otherwise by the test requester, use as exposure conditions those with a pilot flame (see 8.3).

Mode 1:	Irradiance:	25 kW/m ² , with pilot flame
Mode 2:	Irradiance:	50 kW/m ² , with pilot flame
Mode 3:	Irradiance:	25 kW/m ² , without pilot flame
Mode 4:	Irradiance:	50 kW/m ² , without pilot flame

11.9.2 If during a test, one or more of the three replicate specimens show any of the following behavior: a specimen being displaced from the zone of controlled irradiance so as to touch the pilot burner or the pilot flame, extinction of the pilot flame (even for a short period of time) in the flaming mode,³⁵ molten material overflowing the specimen holder, or self-ignition in the nonflaming mode, then an additional specimen of the identical preconditioned sample shall be tested in the test mode in which the unusual behavior occurred. A maximum of six specimens is allowed to be tested for any one test mode. Data obtained from the improper tests noted above shall not be incorporated in the averaged data, but the occurrence shall be reported. The test method is not suitable if three of the specimens tested in any one specific test mode show any of the above characteristics.³⁶

11.9.3 For each individual specimen, determine the percentage value of light transmission, from this, calculate the appropriate specific optical density, as given in Section 12. If the value of D_s at 10 min for an individual specimen differs from the average value, for the set of three specimens of which it is part, by more than 50 % of that average for no apparent reason, test an additional set of three specimens, from the same sample in the same mode, and record the average of all six results obtained.

³⁴ The burner is extinguished in order to reduce the likelihood that the air added during venting will create an explosive mixture in the chamber.

³⁵ If a specimen does not cease flaming after the pilot flame goes out, the test results are considered valid.

³⁶ If a thin specimen that had not been cut (see 8.8.4) swells out of the plane, the results from that specimen shall be ignored and an extra cut specimen tested.

³³ If the temperature is too high, use of the exhaust fan to draw in cooler air from the laboratory is an adequate procedure.

12. Calculation

12.1 Specific Optical Density (D_s):

12.1.1 For each specimen, use the set of continuous recorded data of light transmission against time and convert the results at 1.5 min, 4.0 min, and 10.0 min to specific optical density (D_s) by using Eq 1, where $T\%$ is a value of the percent light transmittance, taken from the continuous record.

$$D_s = 132 \log_{10} \frac{100}{T\%} \quad (1)$$

NOTE 2—The factor 132 is derived from the physical characteristics of the chamber by using Eq 2:

$$\frac{V}{A * L} = 132 \quad (2)$$

where:

V is the volume of the chamber, and,

A is the exposed area of the specimen and is the length of the light path.

12.1.2 Add a neutral density correction factor, C_f , to the value of D_s , as determined in 12.1.1. The correction factor depends upon the use of the range-extension filter. The value of C_f is:

12.1.2.1 *Zero*: if the filter is in the light path at the time the transmission was recorded ($T\% \geq 0.01\%$); or, if the photometric system is not equipped with a removable filter; or, if the ND-2 filter is of the correct optical density of two.

12.1.2.2 As determined by the procedure described in 9.5 (and Table 2), if the filter is moved out of the light path at the time it is measured ($T\% < 0.01\%$).

12.2 *Clean Beam Correction Factor (D_c)*—For each specimen, record the value of the “clear beam” reading, T_c , (see 11.7.4) to determine the correction factor D_c . Calculate D_c , as for D_s in 12.1. Do not record the correction factor D_c if it is less than 5 % of the maximum specific optical density as determine from the graph (see 12.1).

12.3 *Mass Loss*—For each specimen tested, calculate and record total mass loss, Δm (in g), by using Eq 3, where m_1 is the initial mass of the specimen, (including the aluminum foil used for testing) (in g), m_2 , is the mass of the specimen after the test (also with all the foil wrappings included) (in g):³⁷

$$\Delta m = m_1 - m_2 \quad (3)$$

13. Test Report

13.1 The following descriptive information shall be included in the test report:

13.1.1 Name and address of the testing laboratory.

13.1.2 Date and identification number of the report.

13.1.3 Name and address of the test requester, when applicable.

13.1.4 Name of manufacturer or supplier of material, product, or assembly tested, if known.

13.1.5 Commercial name or other identification marks and description of the sample.

³⁷ Note that the deposition of smoke particulates on walls and lenses is one of the reasons that, if two materials reach the same peak optical density at different times within the test, they likely are to exhibit different fire performance in terms of smoke obscuration, and possibly in terms of mass optical density.

TABLE 2 Correction Factors With Neutral Density Filter (ND-2) Removed

NOTE 1—Corrections are to be applied to the D_s values equivalent to the 0.01 to 0.001 %T and 0.001 to 0.00001 %T only.

Meter Indication, T_s	Correction Factor, C_f	Optical Density of Neutral Density Filter
31	-27.4	1.79
32	-25.6	1.81
33	-23.8	1.82
34	-22.1	1.83
35	-20.4	1.845
36	-18.8	1.86
37	-17.3	1.87
38	-15.7	1.88
39	-14.2	1.89
40	-12.8	1.90
41	-11.4	1.91
42	-10.0	1.92
43	- 8.6	1.93
44	- 7.3	1.94
45	- 6.0	1.95
46	- 4.8	1.96
47	- 3.5	1.97
48	- 2.3	1.98
49	- 1.2	1.99
50	0.0	2.00
51	+ 1.1	2.01
52	+ 2.2	2.02
53	+ 3.3	2.025
54	+ 4.4	2.03
55	+ 5.5	2.04
56	+ 6.5	2.05
57	+ 7.5	2.06
58	+ 8.5	2.064
59	+ 9.5	2.07
60	+10.5	2.08
61	+11.4	2.086
62	+12.3	2.09
63	+13.2	2.10
64	+14.2	2.107
65	+15.0	2.114
66	+15.9	2.12
67	+16.8	2.13
68	+17.6	2.135
69	+18.5	2.14
70	+19.3	2.146

13.1.6 Full description of the sample, including such aspects as type, form, essential dimension, mass or density, color and coverage rate of any coating.

13.1.7 Full description of specimen construction and preparation (see 8.6 and 8.7).

13.1.8 Face of specimen tested (see 8.6 and 8.7).

13.1.9 Thickness of each specimen tested.

13.1.10 Conditioning of the test specimens.

13.1.11 Date of the test.

13.1.12 Modes of testing, indicating irradiance and use of pilot flame for each specimen. If a nonflaming mode is used, the report shall state that an optional testing mode is used.

13.1.13 Number of specimens tested for each type of exposure.

13.1.14 Test number and any special remarks.

13.2 The following test results shall be included in the test report:

13.2.1 Table of numerical results containing the following information for each specimen tested.

13.2.1.1 Specific optical density at 1.5 min.

- 13.2.1.2 Specific optical density at 4.0 min.
- 13.2.1.3 Specific optical density at 10.0 min.
- 13.2.1.4 Specific optical density at end of test (if test duration is different from 10.0 min).
- 13.2.1.5 Maximum specific optical density.
- 13.2.1.6 Time to ignition.
- 13.2.1.7 Time to maximum optical density.
- 13.2.1.8 Duration of the test.
- 13.2.1.9 The neutral density correction C_f (see 12.1.2).
- 13.2.1.10 The clear beam correction factor, D_c .
- 13.2.1.11 The mass loss, Δm .
- 13.2.1.12 (Optional) If mass optical density is measured, the information required in A1.8.

13.2.2 *Graphical Results*—Plot of specific optical density against time for each specimen tested.

13.2.3 Descriptive Results:

13.2.3.1 All available information required in 8.7 (regarding specimen preparation and coatings used, if applicable) and in 11.6 (observations regarding burning characteristics of the specimens and any events of special interest during the tests).

13.2.3.2 Details of any invalid tests with reasons for them being invalid (see 5.5.1 and 11.9.2).

14. Precision and Bias

14.1 *Precision*—Tables A3.1 and A3.2 in Annex A3, contain information on repeatability and reproducibility, from a preliminary international interlaboratory evaluation, in which batches of 16 materials were tested in accordance with this test method by eight laboratories in six countries, for plastic materials (Table A3.1) and building materials (Table A3.2). Additional information on repeatability in a single laboratory for two wood samples is presented in Table A3.3, and repeatability information from another laboratory, which tested six building products, in Table A3.4. Overall the results of these preliminary studies indicate that the average coefficient of variability (CV) for repeatability is 14.4, while the average coefficient of variability for reproducibility in the international study is 49.0. Results from a more definitive precision study will be made available after a round robin evaluation has been completed.

14.2 *Bias*—The bias of this test method is unknown.

15. Keywords

15.1 cone heater; fire; fire-test-response characteristic; optical density; smoke; smoke obscuration

ANNEXES

(Mandatory Information)

A1. Determination of mass optical density (optional measurements)

A1.1 *Mass Optical Density as Measured by This Test Method (Optional Measurements)*—The values of mass optical

density (MOD) determined by this test method are specific to the specimen used in the form and thickness tested and are not to be considered inherent or fundamental properties.

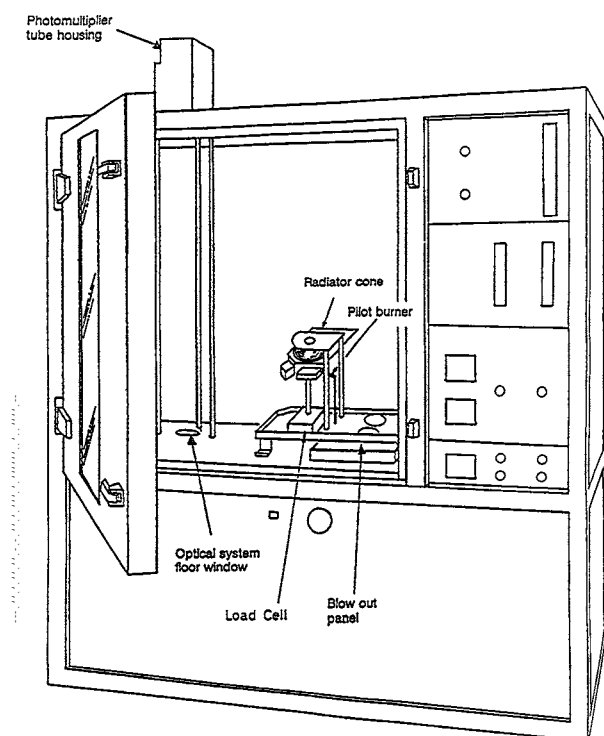


FIG. A1.1 Typical Arrangement of Test Chamber With Load Cell

A1.2 *Principles of the Test*—The conditions of thermal exposure and of smoke collection are the same as those in the main body of the test method. Additional mass loss measurements, optionally, are conducted on the specimen during the test. From these measurements, it is possible to obtain a mass loss/time curve and to calculate mass optical density.

A1.3 *Test Specimen*—The same specifications on suitability of materials, products, or assemblies, apply here than in the main body of the test method (see Section 8). Similarly, the same number of specimens, their preparation and conditioning also applies (see Section 10).

A1.4 Ancillary Equipment:

A1.4.1 The load cell shall have a measuring range of 500 g, and a weighing accuracy of ± 0.1 g. Mount the load cell in an enclosure (see Figs. A1.1-A1.4) with a close-fitting labyrinth seal between the sample support rod and the enclosure, to minimize ingress of smoke particles and aggressive combustion products.^{38,39}

³⁸ The load cell assembly should be easily removable from the smoke chamber, so that the mandatory test procedure can be performed without unnecessary exposure of the load cell, if mass optical density data is not required.

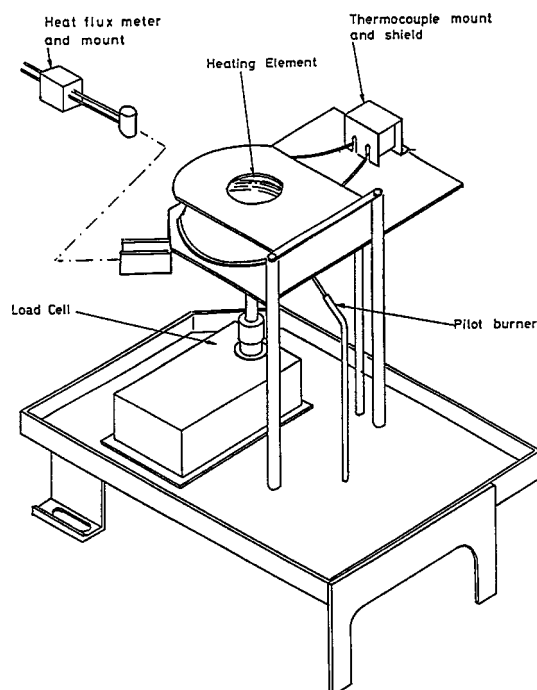


FIG. A1.2 Typical Framework for Support of Radiator Cone, Specimen, Flux Meter, and Load Cell

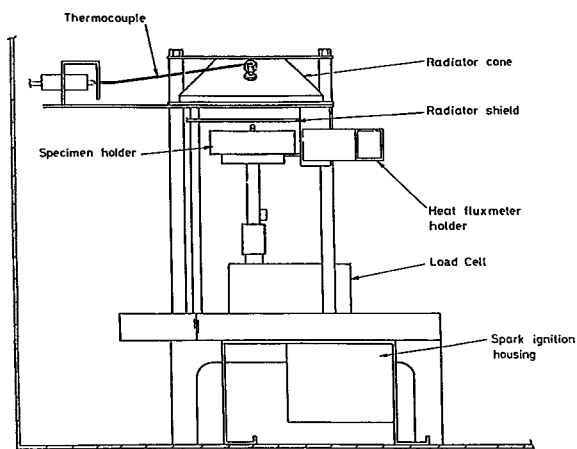


FIG. A1.3 Typical Arrangement of Radiator Cone, Specimen Holder, Radiator Shield, and Load Cell (Side View)

A1.4.2 The load cell enclosure shall be fitted with one fixed foot and two adjustable feet, to level the unit on the baseplate. The load cell also shall have a means to centralize the load cell assembly beneath the cone radiator.

A1.4.3 The load cell shall have a safe operating temperature range between 15 and 70 °C [59 to 158 °F]. A mineral fiberboard shield shall be positioned over the top and sides of the load cell enclosure during thermal exposure of the test specimen, so that excessive temperature rise within the enclosure is prevented, and drift of the load cell is avoided.

A1.4.4 The load cell shall be connected to a controller, which drives the load cell, and which is situated externally to

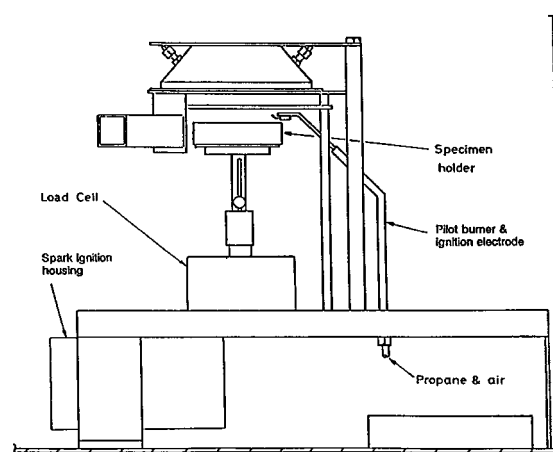


FIG. A1.4 Typical Arrangement of Radiator Cone, Specimen Holder, Radiator Shield, and Load Cell (Front View)

the smoke chamber. This controller shall be preferably fitted with a digital mass display, a scaleable millivolt output and a sample tare facility.

A1.5 *Calibration Procedures*—The load cell calibration shall be checked with standard reference weights, in the range of test specimen mass, before each series of tests.

A1.6 *Test Procedure*—Conduct the test in the same manner as detailed in Section 10, with the added precaution of ensuring that the load cell measurements are conducted properly.

A1.7 Calculation of Mass Optical Density (MOD):

A1.7.1 For each specimen, calculate the mass optical density (in m²/kg), at 10 min, using Eq A1.1:

$$MOD = \frac{D}{L} * \frac{V}{\Delta m \times 0.001} \quad (A1.1)$$

where:

D = the optical density of smoke;
 L = the length of light path (0.914 m);
 V = the volume of the chamber (0.51 m³); and,
 Δm = the mass loss of the test specimen ($\Delta m = m_i - m_f$), in g). The optical density of smoke is calculated by means of Eq A1.2:

$$D = \log [I_0 / I] \quad (A1.2)$$

where:

I and I_0 = the light intensity for a parallel light beam having traversed a certain length of smoky environment and reaching photodetector and the light intensity for a beam of parallel light rays, measured in a smoke free environment, with a detector having the same spectral sensitivity as the human eye and reaching the photodetector, respectively.⁴⁰

A1.8 Test Report:

³⁹ Figs. A1.1-A1.4 differ from Figs. 1 and 4, Fig. 5, and Fig. 7 in that they show the location of the (optional) load cell.

⁴⁰ It is possible to calculate the mass optical density at times other than 10 min by using the specimen mass/time graph recorded during the test.

A1.8.1 The test report shall include all the information required in the mandatory part of the test method, as well as, for each specimen tested:

A1.8.1.1 Mass optical density at 10 min from the start of the test.

A1.8.1.2 Graph of specimen mass against time.

A2. Calibration of the working heat-flux meter

A2.1 The calibration of the heat-flux meter shall be checked, whenever a recalibration of the apparatus is carried out, by comparison with two instruments of the same type as the working heat-flux meter and of similar range, held as reference standards and not used for any other purpose. One of the heat flux meter reference standards shall be calibrated fully at an accredited laboratory at yearly intervals. This meter shall be used to calibrate the heater temperature controller (Figs. 4 and 5). It shall be positioned at a location equivalent to the center of the specimen face during this calibration. One option

for making the intercomparison of working and reference standard heat-flux meters required in 9.8, is the use of the conical heater (6.3.1), with each heat flux meter mounted in turn in the calibration position (6.3.1.2), care being taken to allow the whole apparatus to attain thermal equilibrium. Alternatively, use an apparatus specially built for comparative purposes, for example as described in BS 6809.⁴¹

⁴¹ The use of two reference standards rather than one provides a greater safeguard against change in sensitivity of the reference instruments.

A3. Variability in the Specific Optical Density of Smoke Measured in This Single-Chamber Test

A3.1 A preliminary interlaboratory trial has been carried out in which replicate batches of 16 materials are tested in accordance with this test method by eight laboratories (in six countries). This preliminary interlaboratory trial showed that the specific optical densities D_s (at 10 min) of some materials had a higher relative variability than those of others. The relative variability increased particularly for those materials which did not ignite readily at an incident heat flux of 25 kW/m², and for those materials which showed higher D_s (at 10 min) values in the nonflaming mode than in the flaming mode.

A3.2 The preliminary interlaboratory trial has demonstrated the ability of this test apparatus to discriminate between materials, which generate different levels of smoke. Tables

A3.1 and A3.2 present the repeatabilities and reproducibilities of D_s (at 10 min) for five plastics and five building materials, as derived in accordance with the statistical analysis in ISO 5725.

A3.3 Repeatability (r) is the value below which the difference between two D_s (at 10 min) values obtained with the same method on identical test sample, under the same conditions (same laboratory, same apparatus, same operator, within a short interval of time), may be expected to lie with a 95 % probability.

A3.4 Reproducibility (R) is the value below which the difference between two D_s (at 10 min) values obtained with the

TABLE A3.1 Repeatabilities and Reproducibilities of Specific Optical Density for Some Plastics

NOTE 1—pf indicates test carried out with pilot flame.

Material	Thickness, mm	Irradiance, kW/m ²	Mean, D_s (10)	Repeatability (Within Laboratories)		Reproducibility (Between Laboratories)	
				r	% of mean	R	% of mean
PMMA	1.0	25	11	4	38	10	91
		25 + pf	55	13	24	29	53
		50	54	11	20	17	32
ABS	1.1	25	312	77	25	311	100
		25 + pf	441	146	33	205	46
		50	435	102	23	192	44
Polyurethane rigid foam (28 kg/m ³)	25.0	25	49	16	32	61	124
		25 + pf	48	24	51	26	54
		50	145	48	33	97	67
Polyurethane flexible foam (27 kg/m ³)	25.0	25	178	49	27	114	64
		25 + pf	80	28	35	56	70
		50	127	46	36	80	63
Expanded polystyrene (nonfire retardant; 14 kg/m ³)	25.0	25	112	75	67	196	175
		25 + pf	102	75	74	130	128
		50	270	88	33	195	72

TABLE A3.2 Repeatabilities and Reproducibilities of Specific Optical Density for Some Building Materials

NOTE 1—pf indicates test carried out with pilot flame.

Material	Thickness, mm	Irradiance, kW/m ²	Mean, D_s (10)	Repeatability (Within Laboratories)		Reproducibility (Between Laboratories)	
				r	% of mean	R	% of mean
Pine	12.1	25	403	97	24	300	74
		25 + pf	26	15	55	56	211
		50	196	191	98	191	98
Chipboard	12.2	25	411	47	12	187	45
		25 + pf	58	59	102	88	153
		50	481	96	20	464	97
Plywood	4.2	25	251	31	12	132	52
		25 + pf	33	15	47	58	175
		50	113	58	51	82	72
Medium density fiberboard	11.9	25	420	127	30	281	67
		25 + pf	68	42	62	72	106
		50	688	114	17	413	60
Paper-faced plasterboard	12.7	25	20	8	42	21	107
		25 + pf	8	8	104	25	314
		50	17	11	64	23	132

TABLE A3.3 Repeatability Experiments Using Wood Samples in a Single Laboratory

NOTE 1—AVG: average; STD: standard deviation; CV%: coefficient of variance.

Material	Douglas Fir Plywood	Red Oak Flooring
Incident Flux: 25 kW/m ² , NF		
D_m (AVG)	496	475
D_m (STD)	47	9
D_m (CV%)	9	2
D_m /g (mass loss) (AVG)	24.2	22.1
D_m /g (mass loss) (STD)	4.7	7.3
D_m /g (mass loss) (CV%)	20	33
Incident Flux: 35 kW/m ² , NF		
D_m (AVG)	475	461
D_m (STD)	11	12
D_m (CV%)	2	3
D_m /g (mass loss) (AVG)	19.9	11.9
D_m /g (mass loss) (STD)	3.4	2.7
D_m /g (mass loss) (CV%)	17	23
Incident Flux: 40 kW/m ² , NF		
D_m (AVG)	491	461
D_m (STD)	13	22
D_m (CV%)	3	5
D_m /g (mass loss) (AVG)	22.3	13.4
D_m /g (mass loss) (STD)	4.5	6.0
D_m /g (mass loss) (CV%)	20	45
Overall Statistics		
D_m (AVG)	487	466
D_m (STD)	29	16
D_m (CV%)	6	3
D_m /g (mass loss) (AVG)	22.1	15.8
D_m /g (mass loss) (STD)	4.1	7.1
D_m /g (mass loss) (CV%)	19	45

same method on an identical test sample, under different conditions (different laboratories, different operators, different apparatuses), may be expected to lie with a 95 % probability.

A3.5 The preliminary interlaboratory trial has suggested that it is not meaningful to quote a single value for the variability of the test. The D_s (at 10 min) data shows that smoke generation depends upon the ignition behavior of the materials

(among other factors). Since ignition times are sensitive to irradiance (or incident heat flux), it is clear that careful attention must be paid to the measurement of irradiance.

A3.6 A further examination of repeatability also was conducted in a single laboratory for wood samples, and the results are shown in Table A3.3. It is clear from these results that the repeatability of the test method is much better if the

TABLE A3.4 Repeatability Using Products in a Single Laboratory (6)

NOTE 1—E Foam: blended polymeric/rubber compound used as thermal insulation; Sh Fl 1: commercial PVC floor covering, with inorganic felt backing; Fl Tile: commercial-filled PVC floor tile; PP Crp: carpet with polypropylene yarn and scrim; Lens: polymeric material used to cover fluorescent light fixtures; Sh Fl 2: residential unfilled PVC floor covering. AVG: average; STD: standard deviation; CV%: coefficient of variance.

Material	E Foam	Sh Fl 1	Fl Tile	PP Crp	Lens	Sh Fl 2
25 kW/m ² , NF						
Dm AVG	134	266	178	543	333	483
Dm STD	8	9	9	15	17	93
Dm CV%	6	3	5	3	5	19
D10 AVG	111	264	170	521	202	396
D10 STD	5	9	13	12	25	33
D10 CV%	5	4	8	2	12	8
25 kW/m ² , F						
Dm AVG	29	143	97	340	94	476
Dm STD	6	8	37	29	6	20
Dm CV%	19	6	38	9	7	4
D10 AVG	25	121	91	269	72	344
D10 STD	4	7	37	17	5	15
D10 CV%	15	6	40	6	7	4
50 kW/m ² , F						
Dm AVG	125	304	144	388	110	691
Dm STD	7	15	10	31	8	37
Dm CV%	6	5	7	8	2	5
D10 AVG	90	205	118	245	77	418
D10 STD	5	9	9	20	7	15
D10 CV%	5	4	8	8	3	4

materials tested undergo consistent ignition under the conditions used for testing.

A3.7 Six different products were selected for evaluation in a single laboratory. These selections represent typical commercial products that display a wide range of responses when subjected to the heat fluxes and the ignition source employed in this test method. An analysis of the data was conducted as a measure of the repeatability of the test method (see Table

A3.4), which also identifies the products included in the study. The repeatability of the test method for this selection of products is good, as indicated by the calculated coefficient of variance (CV%). Some of the products are difficult to ignite, some of them bulge towards the heater and some of them melt; however, the combination of the cone heater and the horizontal orientation minimizes the effect of these common performance problems.

Copyright ASTM International

APPENDIXES

(Nonmandatory Information)

X1. Smoke Density Chamber:

X1.1 The smoke density chamber test was developed at the National Bureau of Standards and was first described in an ASTM research symposium in 1967 (9). Since that time, there have been numerous publications reporting on its application and on studies of the correlation of results of interlaboratory tests through its use (10-16). Features of a chamber like the one in this test method, which a conical radiant heater, have also been discussed in the literature (17).

X1.2 The method is somewhat like the box type test developed by Rohm and Haas (18), which has since been standardized as Test Method D 2843; however, it provides certain modifications in the nature of specimen exposure and the capability for quantitative measurement of the smoke produced. Advantages provided by use of this test method include the smoke collection chamber is essentially sealed so all smoke produced during a test is retained; only one surface of a test specimen is exposed to fire or radiant heating, thus providing a measure of effectiveness of surface treatment assisting in control of smoke release; a vertical photometer is used as a means for avoiding measurement errors resulting from smoke stratification; provision is included for reporting the result of smoke measurements in terms of specific optical density, which is a measurement of the amount of smoke produced and hence is useful for comparing one material, product, or assembly, against another.

X1.3 Features of This Test Method:

X1.3.1 Two exposure conditions are simulated by the test. These conditions include open flaming combustion in the presence of supporting radiation and radiant heating in the absence of ignition. These two conditions are selected as representative of two types of fire involvement of a product. The irradiance level of 25 kW/m² was selected as the highest for which most cellulose would pyrolyze without self-ignition. This irradiance level is much lower than that which would exist in a compartment after flash-over. It more nearly simulates conditions in the initial stages of a fire; thus, it is representative of a nonflaming fire condition.

X1.3.2 The higher standard heat flux, 50 kW/m², represents what a flaming fire condition.

X1.3.3 The conical heater used is specific to this test method, and is required to yield a maximum imposed heat flux of 50 kW/m² on an exposed specimen area of ca. 4200 mm².

X1.3.4 The primary measurement made during this test method is the amount of light transmitted by an optical system. There is considerable advantage to using specific optical density as a value by which to evaluate results as compared to using percent light transmittance.

X1.3.5 The use of this unit of smoke measurement is based on Bouguer's law of light attenuation which is expressed as in Eq X1.1:

$$T = T_0 e^{-\sigma L} \quad (\text{X1.1})$$

where:

T = the % flux transmittance;
 T_0 (which is equal to 100) = the initial transmitted flux;
 σ = the attenuation coefficient, and
 L = the length of the optical path.
 For a monodispersed aerosol, σ is found to be proportional to the product of the size and the number of particles. The optical density, d , is defined by Eq X1.2:

$$d = \log(100/T) \quad (\text{X1.2})$$

Therefore, the optical density is calculated from Eq X1.3:

$$d = \frac{\sigma L}{\log_e 10} = \frac{\sigma L}{2.303} \quad (\text{X1.3})$$

X1.3.6 While the smoke produced from fire usually does not meet the requirements of a monodispersed aerosol, it has been found to behave in a photometric manner such that, for engineering purposes, optical density may be considered to be roughly proportional to the smoke particulate produced. The fire-test-response characteristic measured in this test method, specific optical density, D_s , has been introduced to provide a conveniently factored rating scale as shown in Eq X1.4:

$$D_s = \frac{V}{AL} d = \frac{V}{AL} \log \left(\frac{100}{T} \right) \quad (\text{X1.4})$$

where:

$(V/AL) = 132$.

X1.3.7 Certain test methods report smoke obscuration simply in terms of light transmission. The problem with such a procedure is that the percent light transmittance is not a reciprocal, linear function of the quantity of smoke produced; that is, the assumption that as the quantity of smoke produced is doubled, the percent light transmittance is cut in half is incorrect.

X1.3.8 The concept of specific optical density, while old in terms of chemical photometric practice, was first introduced for measuring smoke obscuration as part of the smoke density chamber test method (Test Method E 662). It is based on Bouguer's law (Eq X1.1) and permits reporting smoke development in terms that recognize the area of specimen involved, the volume of the chamber, and the optical path length of the

photometer. Specific optical density is a dimensionless quantity, but its value must be recognized as relating to the sample only in the thickness tested. In theory, it has the advantage of providing a basis for estimating the smoke optical density or light-obscuring properties of smoke that can be developed by the same product in other fire-involved areas, different light paths, in another enclosure volume, on the assumption of uniform smoke-air mixing and under similar fire exposure conditions. In practice, techniques for making these estimates have not been developed, because of variations in types of fire exposure; the rate of involvement of a material, product, or assembly, in a fire; the ventilation characteristics of the compartment; and the degree of stratification of the accumulated smoke. In most instances, these are undetermined variables, which greatly influence light transmission through smoke obscuration resulting from a fire.

X1.4 *Factors Influencing this Test Method:*

X1.4.1 During development of the original smoke density chamber test method (Test Method E 662), many factors were considered that could influence the measurements. Some of the more important of these are discussed briefly in the following sections.

X1.4.2 It is observed that, in spite of significant thermal convection mixing, smoke near the top of the cabinet is obviously more dense. This fact is verified by experimental measurements. As a result, it is apparent that a vertical photometer yields a much more representative measurement of smoke accumulation than is provided by a horizontal unit at one position in the chamber.

X1.4.3 Experiments showed that the optical density of the accumulated smoke is sensitive to the spacing between the specimen face and the surface of the radiation source. Experiments suggested that the sensitivity is caused by two effects: closer spacing causes more smoke to be consumed near the heat source; on the other hand, it also reduces air circulation past the specimen, and thus, inhibits open flaming combustion. As a result, if the spacing between sample and heat source is

changed, a small systematic change should be expected in smoke obscuration measurement.

X1.4.4 The use of aluminum foil to wrap the back and edges of the specimen is introduced to provide better standardization because it is found that if smoke particles are allowed to leak out through the back or edges of the specimen holder, the various ways this occurs introduces an undesirable variability in the measurements.

X1.4.5 The set-up in this test method, with the sample being tested horizontally, limits the problem of testing material, products, or assemblies, such as those containing some thermoplastic materials, which can melt and drip away from the heat source.

X1.4.6 The smoke generation from some materials, products, or assemblies, differs significantly depending on whether combustion occurs in a nonflaming or flaming mode. It is important, therefore, to record as much information as possible about the mode of combustion (for example, the presence of flame on the sample surface) during each test.

X1.4.7 Coated and faced samples, including sheet laminates, tiles, fabrics, and other composites secured to a substrate with an adhesive, and composites not attached to a substrate, are subject to delamination, cracking, peeling, or other separations affecting their smoke generation.

X1.4.8 Evaluation of the data obtained for individual specimens, together with the individual masses of the specimens, will assist in assessing the reasons for any observed variability in measurements. Preselection of specimens with identical thickness or mass, or both, will reduce the variability, but is not necessarily truly indicative of the actual variability to be expected from the sample as normally supplied.

X1.4.9 It has been shown, by the use of Test Method E 662, that a number of materials and products exhibit considerable difference in smoke obscuration between the flaming and nonflaming modes. In particular, the nonflaming mode often exhibits higher smoke; thus, use of the nonflaming mode is appropriate when assessing applications involving smoldering combustion.

X2. Radiant Heat-Flux Uncertainties

X2.1 The strategies shown in X2.2 and X2.3 can help to minimize uncertainties in radiant heat flux at the specimen location.

X2.2 New heater elements should be aged before using for test purposes to allow the heater emissivity to stabilize and

minimize drift in the heat flux.

X2.3 It has been found that heat losses down the thermocouple sheath can occur due to a fin effect. If this is a problem, steps should be taken to minimize such losses.

X3. COMMENTARY

X3.1 The visibility in a fire atmosphere will adversely affect the ability of victims to escape and the ability of fire fighters to fight the fire.

X3.2 The test methods used to measure smoke obscuration accompanying a fire can be classified into five categories (5):

- (I) Static small-scale smoke obscuration tests on materials.
- (II) Dynamic small-scale smoke obscuration tests on materials.
- (III) Large-scale smoke obscuration tests on products, not designed for heat release
- (IV) Full-scale tests measuring heat release and smoke release.
- (V) Small scale tests measuring heat release and smoke release.

X3.3 Smoke obscuration measurement test methods.

X3.3.1 There are a significant number of ASTM test methods that measure fire-test-response characteristics associated with smoke obscuration. It is possible to classify most of them as being an example of one of the categories in X3.2.

X3.3.2 Test Methods D 2843 and E 662 are examples of Category (I) tests.

X3.3.3 Test Method D 4100 is an example of a Category (II) test, which measures smoke gravimetrically instead of photometrically, as most other tests do.

X3.3.4 Test Method E 84 is an example of a Category (III) test.

X3.3.5 Test Methods D 5424, E 1537, and E 1590 are examples of Category (IV) tests.

X3.3.6 Test Methods E 906, E 1354, and E 1474 are examples of Category (V) tests.

X3.3.7 The test method described here also is an example of a Category (I) test, which offers solutions to some of the deficiencies described for Test Method E 662 (2-4).

X3.4 *Correlation Between Test Methods:*

X3.4.1 Little information exists about correlations between test methods measuring smoke obscuration. It has been found that there is good correlation between data from Test Method E 906 and Test Method E 1354 (7). It also has been found that there is good correlation between data from Test Method D 5424 and E 1354 (8), while there is poor correlation between the data from Test Method E 662 and either Test Method E 906 or E 1354 or a fully lined room, as discussed in Guide E 603 (7, 9).

X3.4.2 The test method described here would be expected to offer more adequate results than Test Method E 662, principally because of two features: the capability of using high incident heat fluxes, and the use of horizontal samples, which do not lose material due to melting and dripping.

X3.5 If the heat-flux meter finish has a relatively flat spectral absorptivity in the range of 2-14 μm , that would decrease heat flux setting uncertainty.

X3.6 The exact temperature measured by the thermocouple shown in Fig. 4 is not critical, as that temperature value is used only for assessment of the heat flux on the test specimen, and the critical issue is to ensure that it is consistent during the calibration and during the test.

REFERENCES

- (1) Grand, A.F., "Defining the Smoke Density Hazard of Plastics," *J. Fire and Flammability*, 7, 217-233, (1976).
- (2) Breden, L.H. and Meisters, M., "The Effect of Sample Orientation in the Smoke Chamber," *J. Fire Flammability*, 7, 234-47 (1976).
- (3) Babrauskas, V., "Application of Predictive Smoke Measurements," *J. Fire Flammability* 12, 51-64 (1981).
- (4) Quintiere, J.G., "Smoke Measurements: An Assessment of Correlations Between Laboratory and Full-scale Experiments," *Fire and Materials*, 6, 145-60 (1982).
- (5) Hirschler, M.M., "Analysis of an Attachment for Use with the National Bureau of Standards Smoke Density Chamber to Enable Measurements of Smoke Obscuration to Be Done at Different Orientations," *Fire and Materials*, 17, 173-83 (1993).
- (6) Fritz, T.W. and Hunsberger, P.L., "Smoke Chamber Measurements," 20th International Conference Fire Safety, Ed. C.J. Hilado, Jan. 9-13, 1995, San Francisco, CA, p. 200-211 (1995).
- (7) Hirschler, M.M., "How to Measure smoke obscuration in a manner relevant to fire hazard assessment: Use of Heat Release Calorimetry Test Equipment," *J. Fire Sciences*, 9, 183-222 (1991).
- (8) Hirschler, M.M., "Can Heat Release Really Predict the Flame Spread of Electrical cables?," 2nd International Fire Materials Conference and Exhibition, Crystal City, VA, Sept. 23-24, 1993, pp. 181-90.
- (9) Hirschler, M.M., Comparison of Smoke Release Data from Full Scale Room Tests with Results in the Cone Calorimeter and the NBS Smoke Chamber," *Proc. Interflam '93*, March 30-1 April 1993, Oxford, UK, pp. 203-212, *Interscience Communications*, London, UK (1993).
- (10) Gross, D., Loftus, J.J., and Robertson, A.F., "Method for Measuring Smoke from Burning Materials," *Symposium on Fire Test Methods-Restraint and Smoke*, ASTM STP 422, ASTM, 1966, p. 166.
- (11) Gross, D., Loftus, J.J., Lee, T.G., and Gray, V.E., "Smoke and Gases Produced by Burning Aircraft Interior Materials," NBS Bldg. Sci. Series, BSS 18, U.S. Government Printing Office, Washington, DC, February 1969.
- (12) Brenden, J.J., "Usefulness of a New Method for Smoke Yield from Species and Panel Products," *Forest Products Journal*, FPJOA, Vol 21, 1971, pp. 23-8.
- (13) Lee, T.G., "Interlaboratory Evaluation of Smoke Density Chamber," NBS Tech. Note 708, December 1971.
- (14) Lee, T.G., "The Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Materials," NBS Tech. Note 757, January 1973.
- (15) ASTM Committee E05.2 "Interlaboratory Test Data for the Smoke Chamber Test Method," RR:E-5-1002, 1976.
- (16) Gaskill, J.R., "Smoke Development in Polymers During Pyrolysis or Combustion," *Journal of Fire and Flammability*, July 1970, pp. 183-216.
- (17) Chien, W.P. and Seader, J.D., "Prediction of Specific Optical Density for a Smoke Obscuration in an NBS Smoke Density Chamber," *Fire*

- Technology, FITCA, Vol 11, August 1975, pp. 206–217.
- (18) Cornelissen, A.A., “Smoke Release Rates: *Modified Smoke Chamber Versus Cone Calorimeter - Comparison of Results*,” *J. Fire Sciences*, Vol 10, pp. 3–19 (1992).
- (19) Bartosic, A.J. and Rarig, F.J., “Evaluation of the XP2 Smoke Density Chamber,” *Symposium on Fire Test Methods-Restraints and Smoke*, ASTM STP 422, ASTM, 1966, p. 106.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).

Copyright ASTM International
 Provided by IHS under license with ASTM
 No reproduction or networking permitted without license from IHS